US011895651B2

(12) **United States Patent**
Chae et al.

(10) **Patent No.: US 11,895,651 B2**
(45) **Date of Patent: Feb. 6, 2024**

(54) **WIRELESS COMMUNICATIONS FOR A SIDELINK**

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(73) Assignee: **Comcast Cable Communications, LLC**, Philadelphia, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 318 days.

(21) Appl. No.: **16/864,745**

(22) Filed: **May 1, 2020**

(65) **Prior Publication Data**

US 2020/0351859 A1 Nov. 5, 2020

Related U.S. Application Data

(60) Provisional application No. 62/842,235, filed on May 2, 2019.

(51) **Int. Cl.**
H04W 72/20 (2023.01)

(52) **U.S. Cl.**
CPC ***H04W 72/20*** (2023.01)

(58) **Field of Classification Search**
USPC 370/229, 230, 230.1, 252, 311, 328, 329, 370/330, 395.4, 468
See application file for complete search history.

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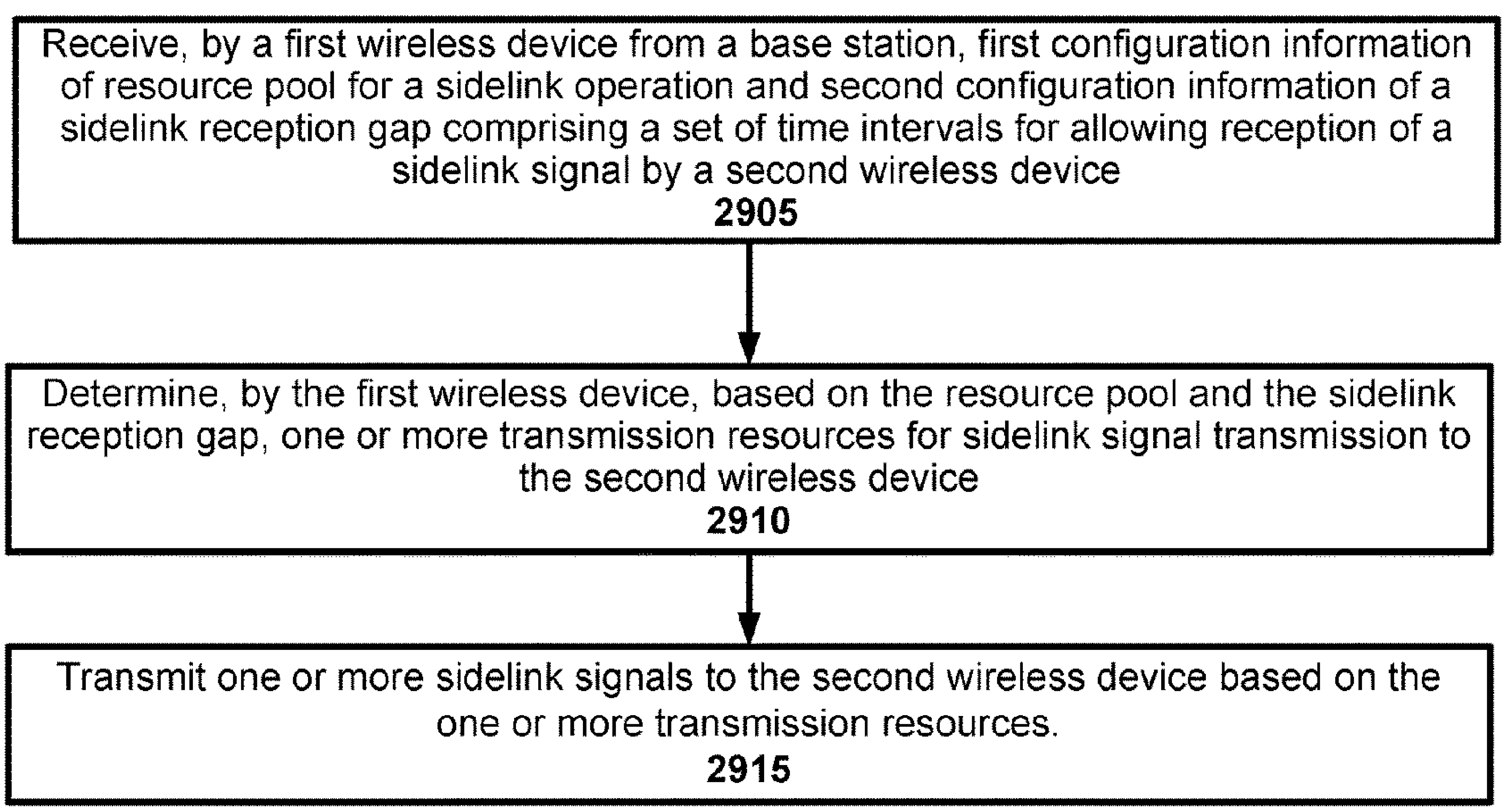
Primary Examiner — Nguyen H Ngo
(74) *Attorney, Agent, or Firm* — Banner & Witcoff, Ltd.

(57) **ABSTRACT**

Wireless communications for a sidelink are described. A wireless devices and/or a base station may determine at least one resource and/or time period for communications via a sidelink. The base station and/or the wireless device may schedule sidelink communication, based on the determined resource(s) and/or time period(s), which may increase the likelihood of successful sidelink communications between wireless devices.

28 Claims, 33 Drawing Sheets



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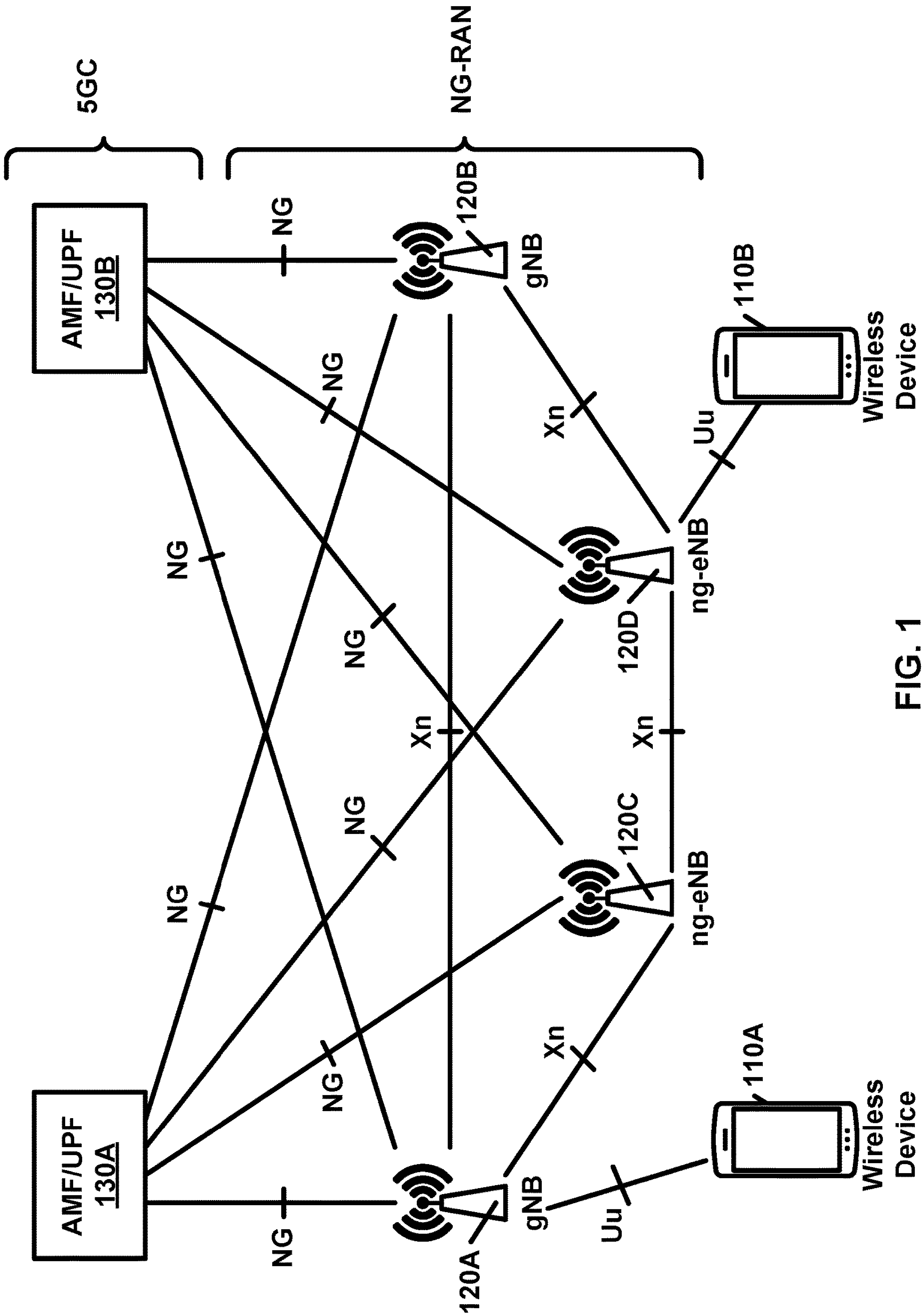
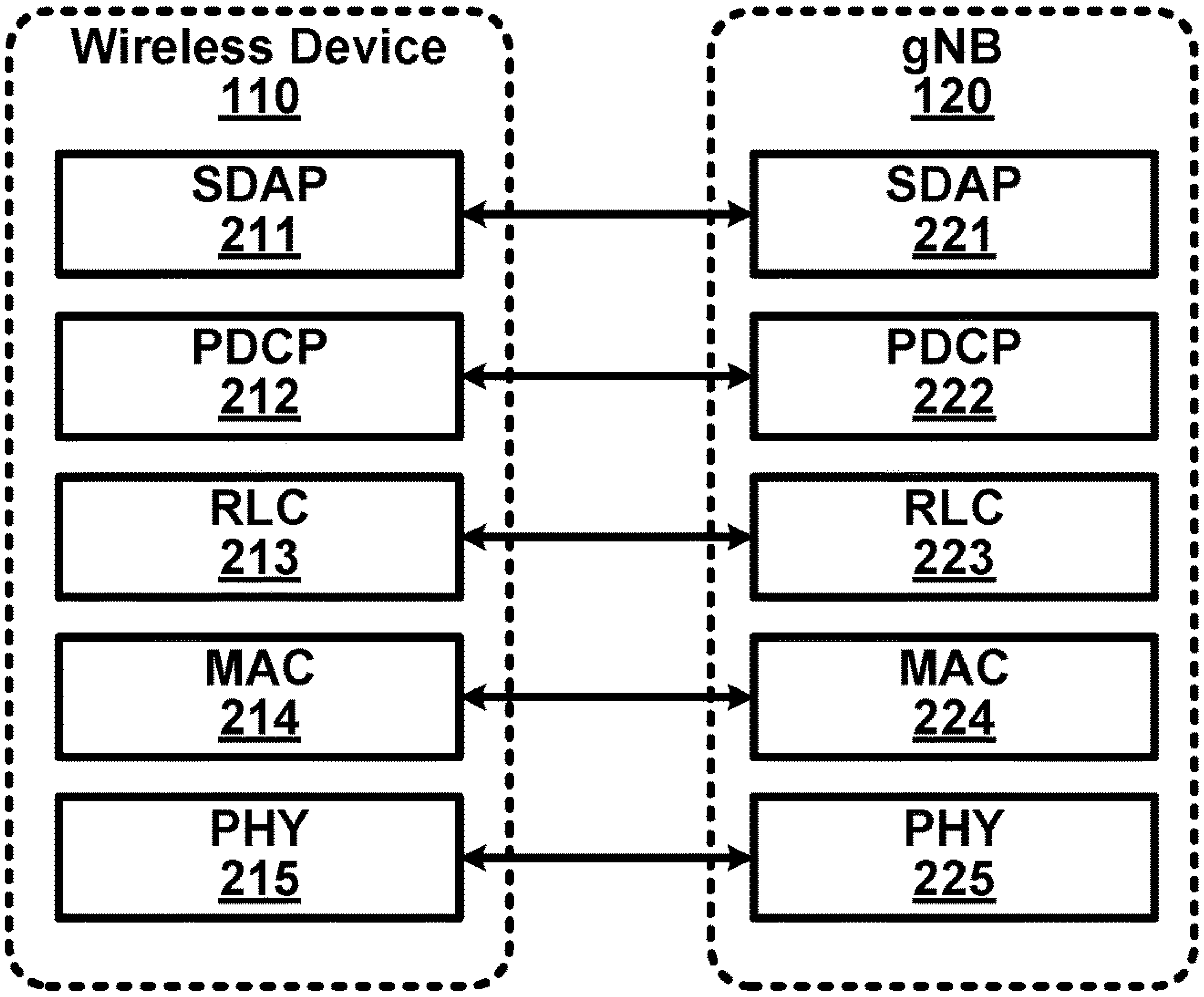
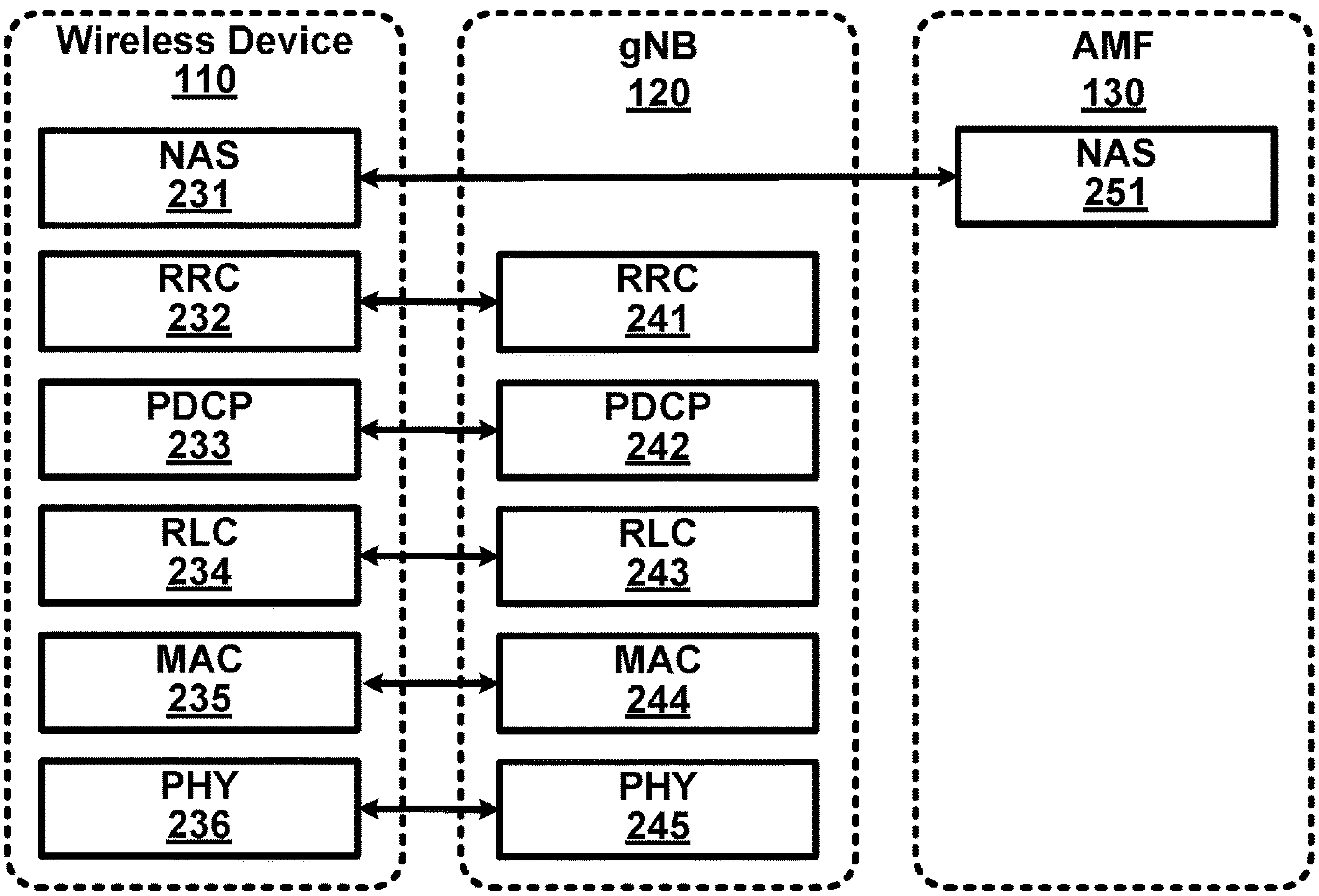

5GC
NG-RAN
AMF/UPF
130B
AMF/UPF
130A
NG
NG
NG
NG
NG
NG
NG
NG
Xn
Xn
Xn
Xn
Uu
Uu
gNB
120B
gNB
120A
ng-eNB
120C
ng-eNB
120D
110A
Wireless
Device
110B
Wireless
Device

FIG. 1



User Plane Protocol Stack

FIG. 2A



Control Plane Protocol Stack

FIG. 2B

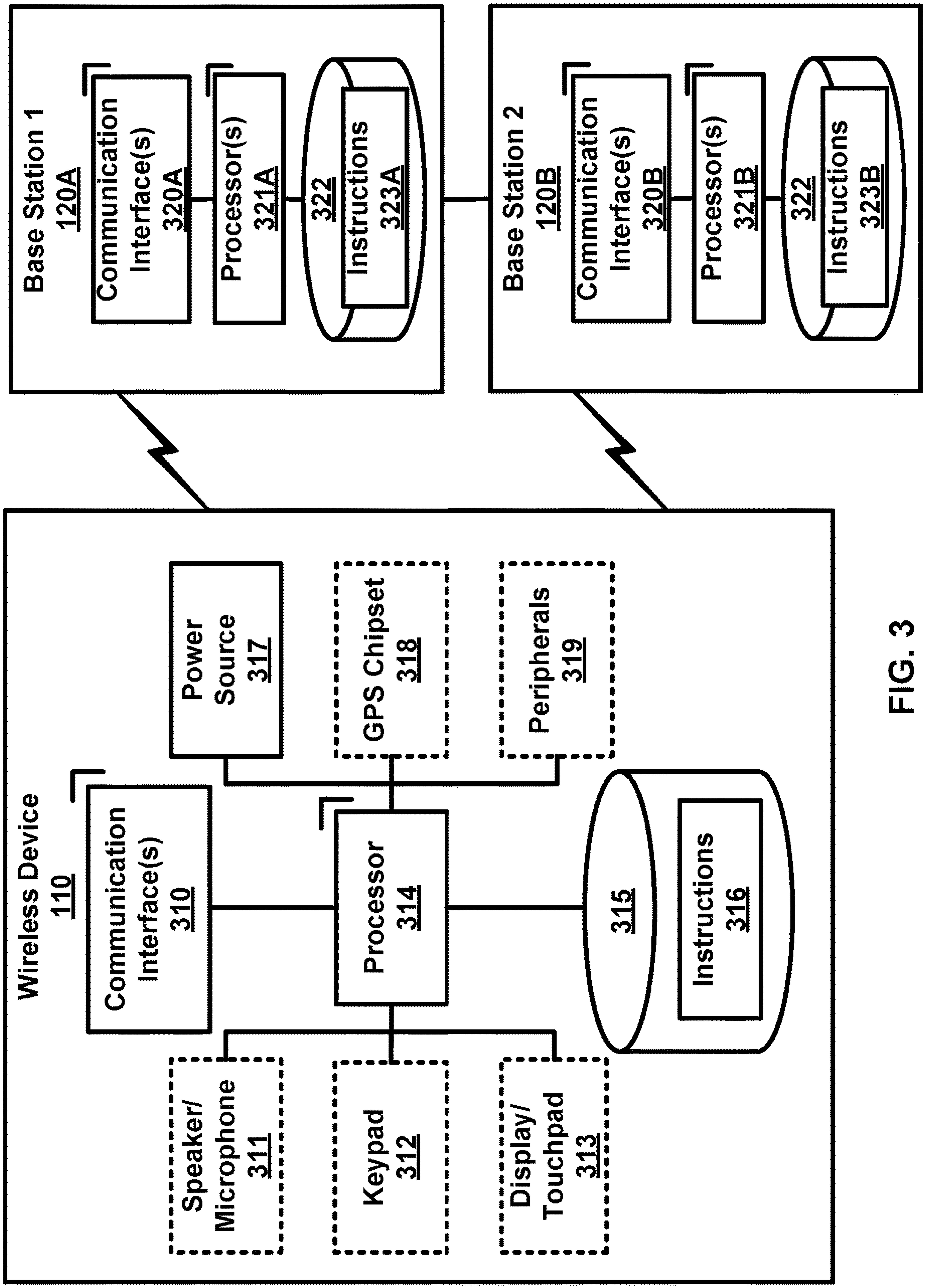

Base Station 1
120A
Communication Interface(s)
320A
Processor(s)
321A
322
Instructions
323A
Base Station 2
120B
Communication Interface(s)
320B
Processor(s)
321B
322
Instructions
323B
Wireless Device
110
Communication Interface(s)
310
Power Source
317
GPS Chipset
318
Peripherals
319
Processor
314
315
Instructions
316
Speaker/ Microphone
311
Keypad
312
Display/ Touchpad
313

FIG. 3

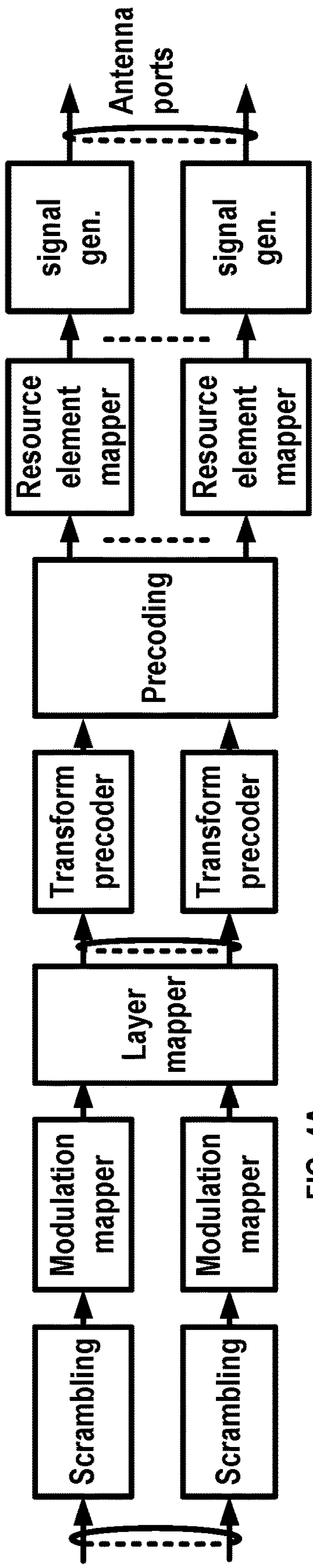


FIG. 4A

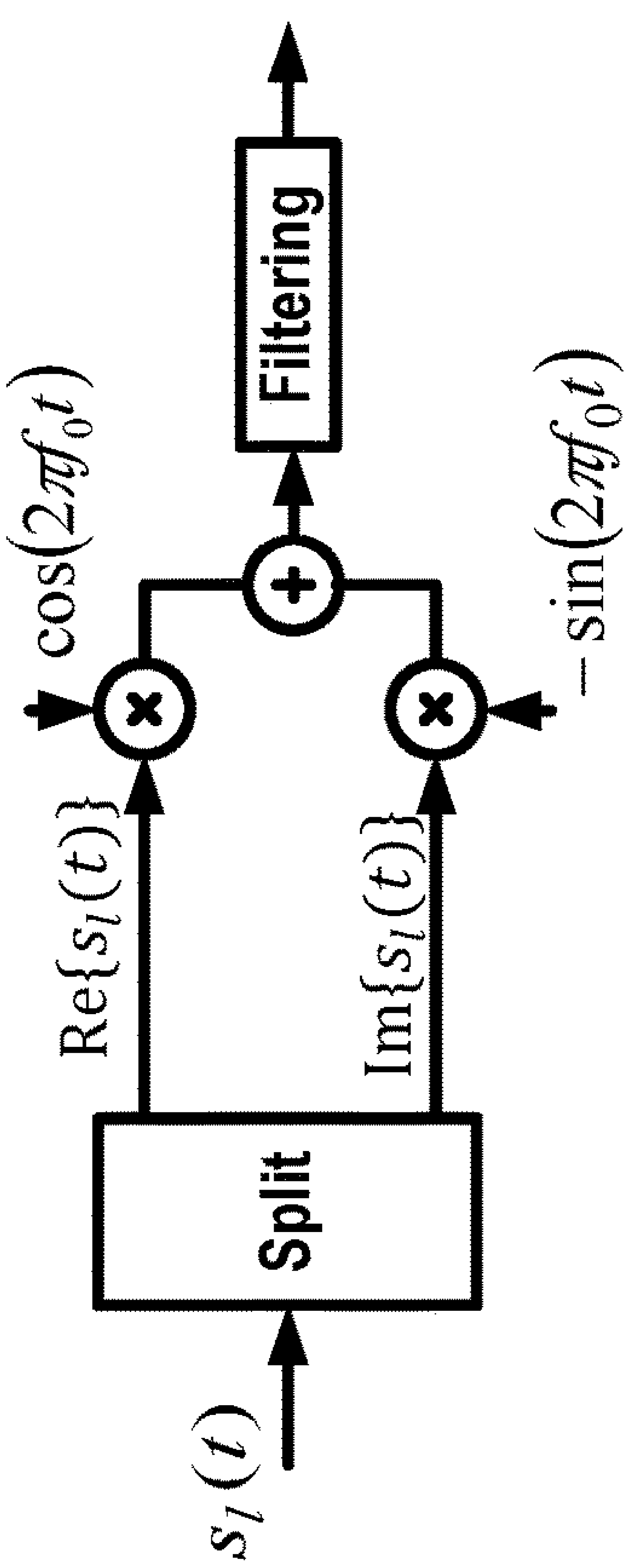


FIG. 4B

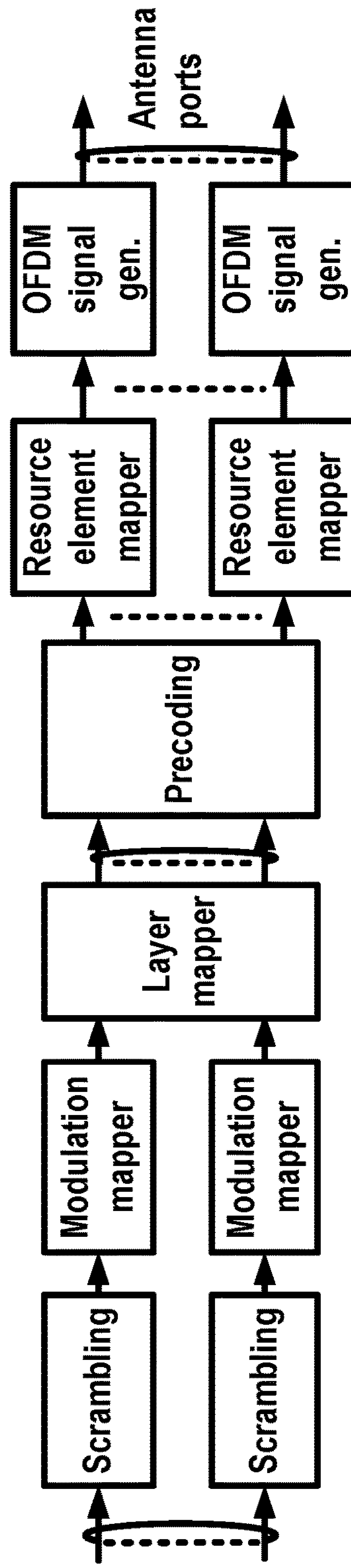


FIG. 4C

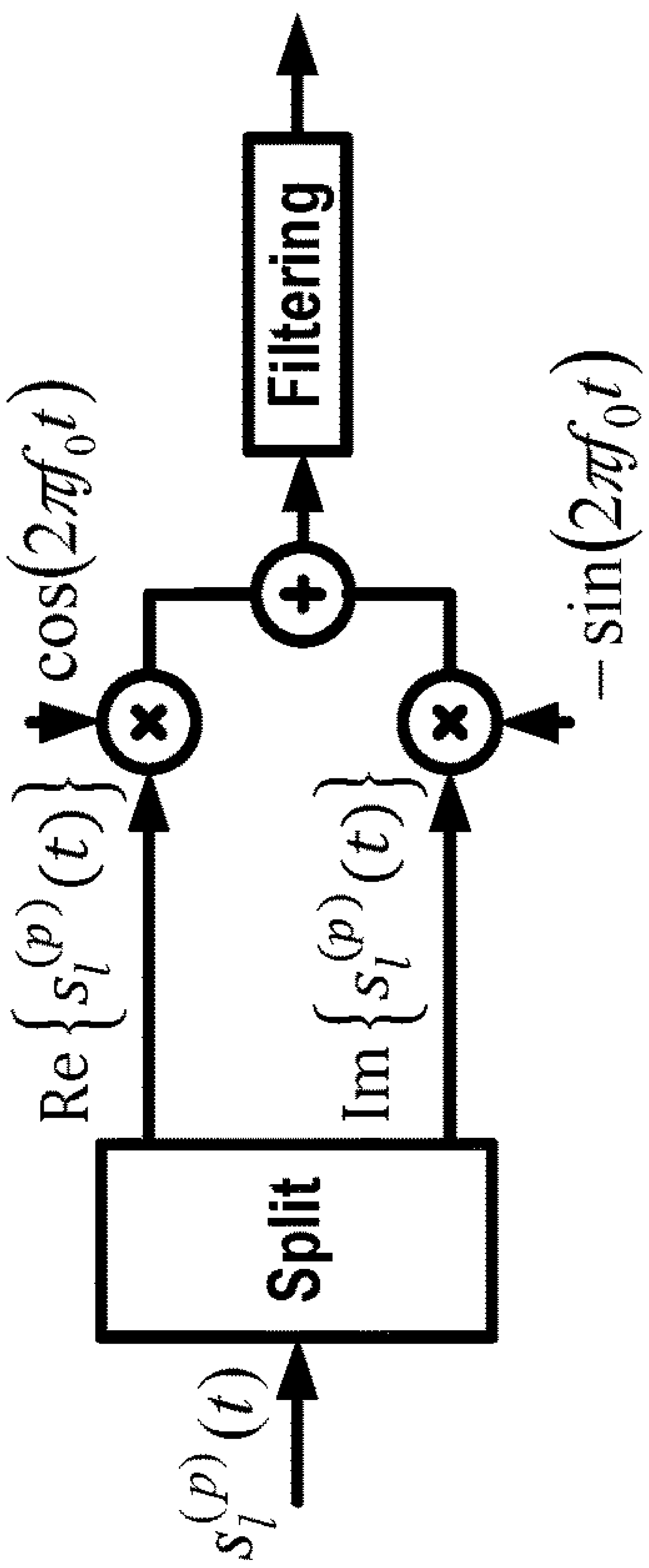


FIG. 4D

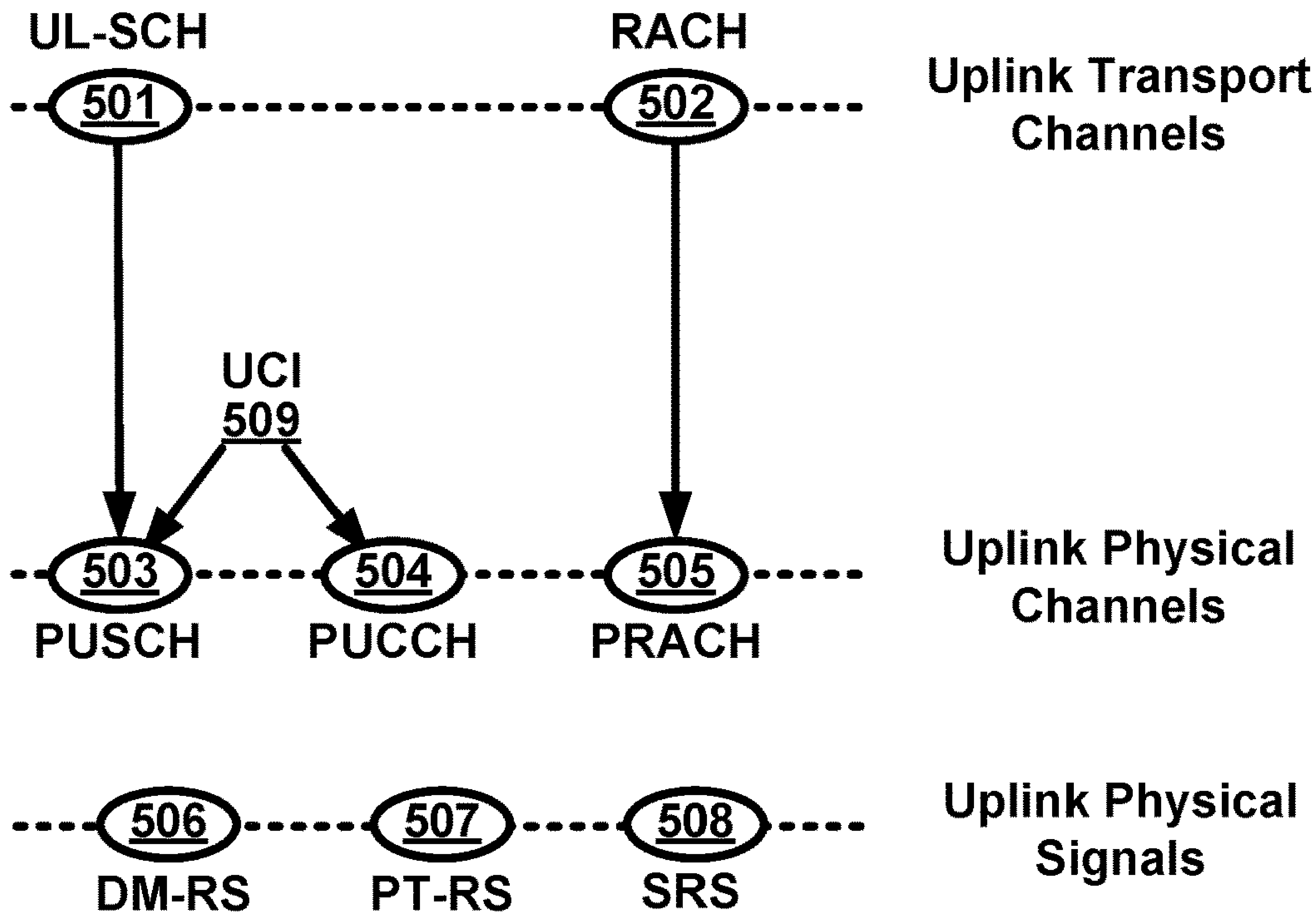

UL-SCH
RACH
501
502
Uplink Transport Channels
UCI
509
503
504
505
PUSCH
PUCCH
PRACH
Uplink Physical Channels
506
507
508
DM-RS
PT-RS
SRS
Uplink Physical Signals

FIG. 5A

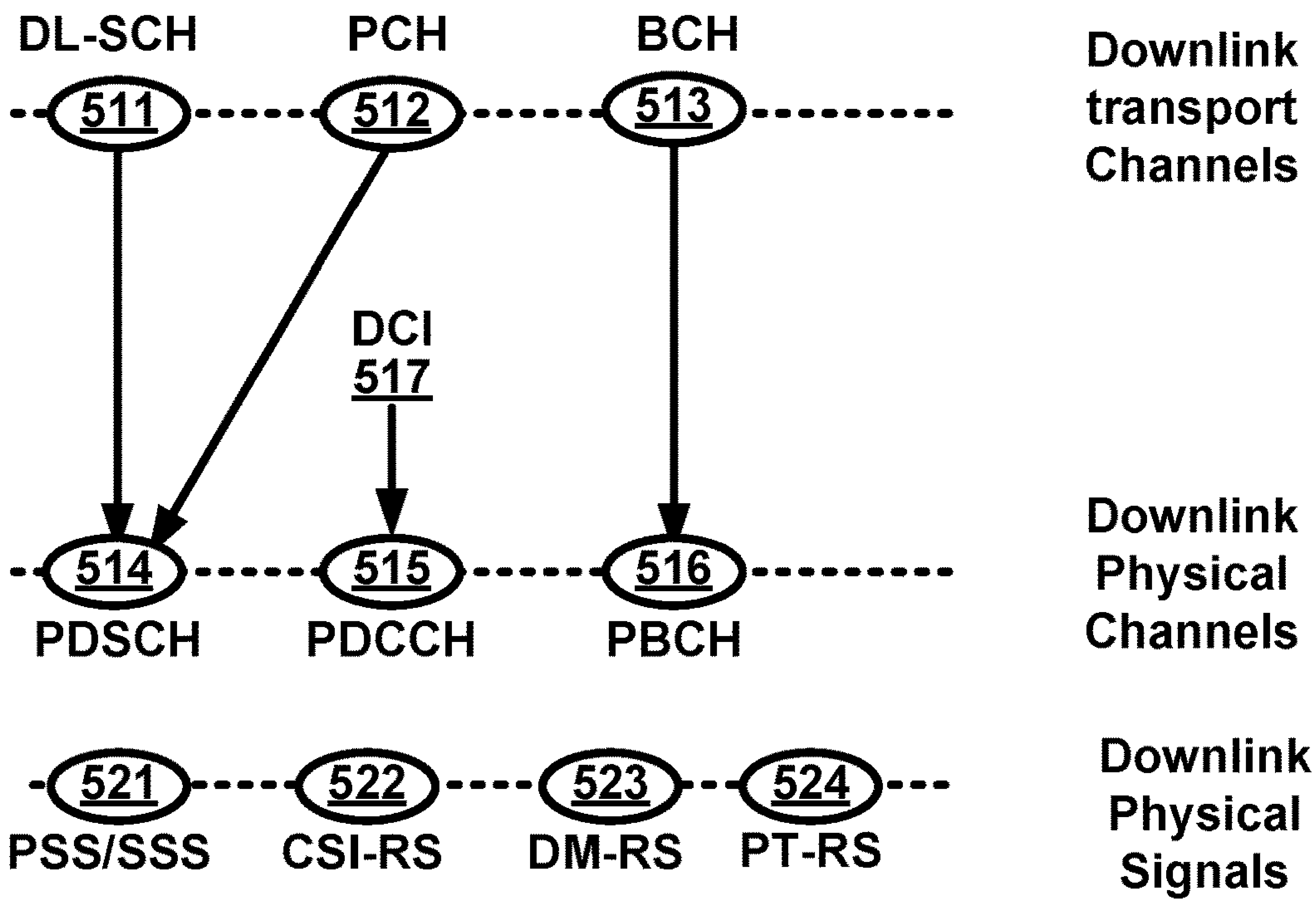

DL-SCH
PCH
BCH
511
512
513
Downlink transport Channels
DCI
517
514
515
516
PDSCH
PDCCH
PBCH
Downlink Physical Channels
521
522
523
524
PSS/SSS
CSI-RS
DM-RS
PT-RS
Downlink Physical Signals

FIG. 5B

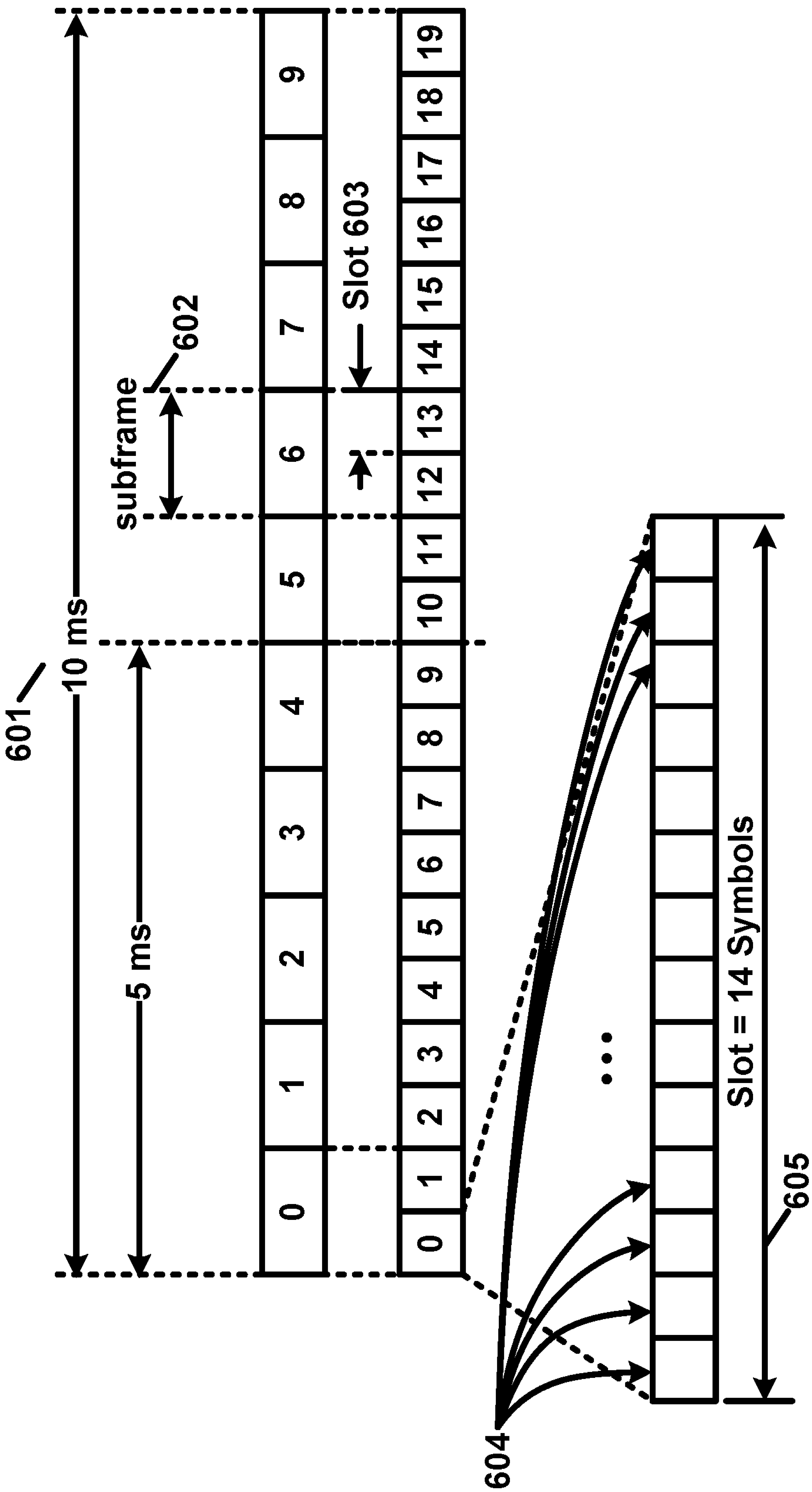

601
10 ms
5 ms
subframe
602
Slot 603
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
604
Slot = 14 Symbols
605

FIG. 6

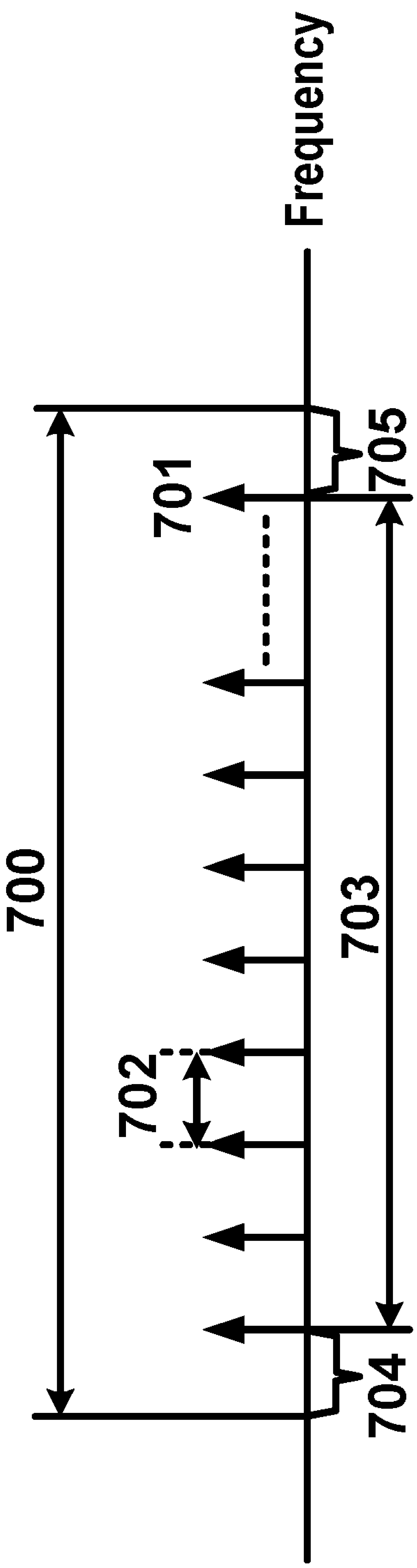

Frequency
700
701
702
703
704
705

FIG. 7A

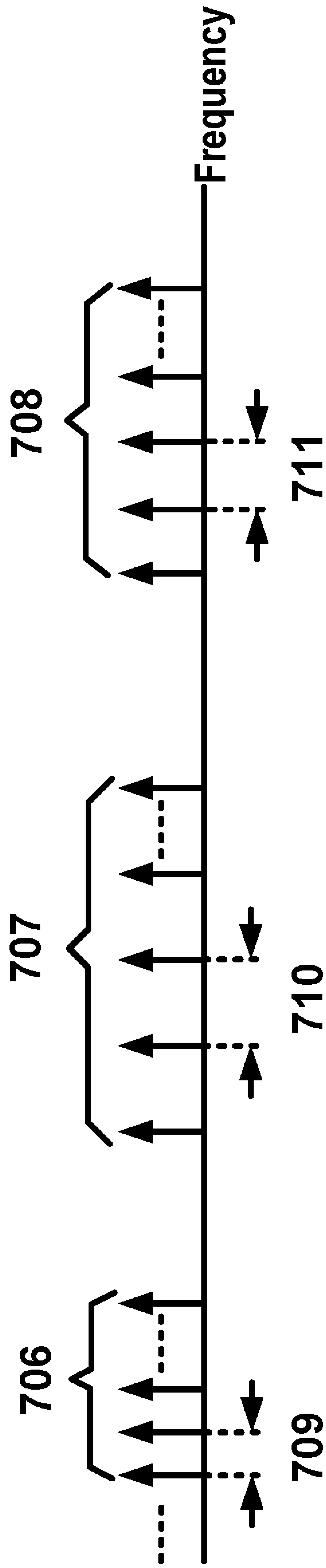

Frequency
706
707
708
709
710
711

FIG. 7B

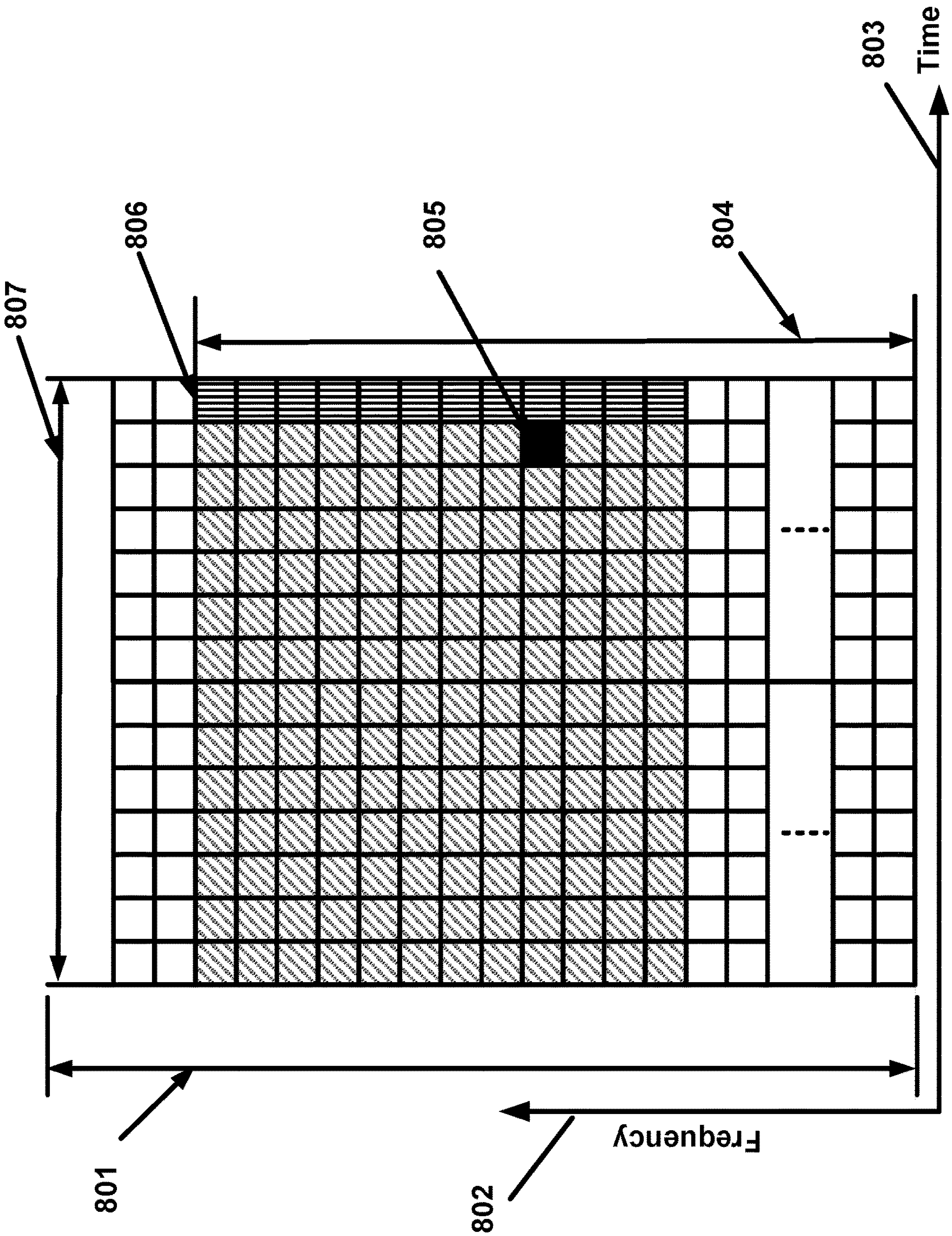
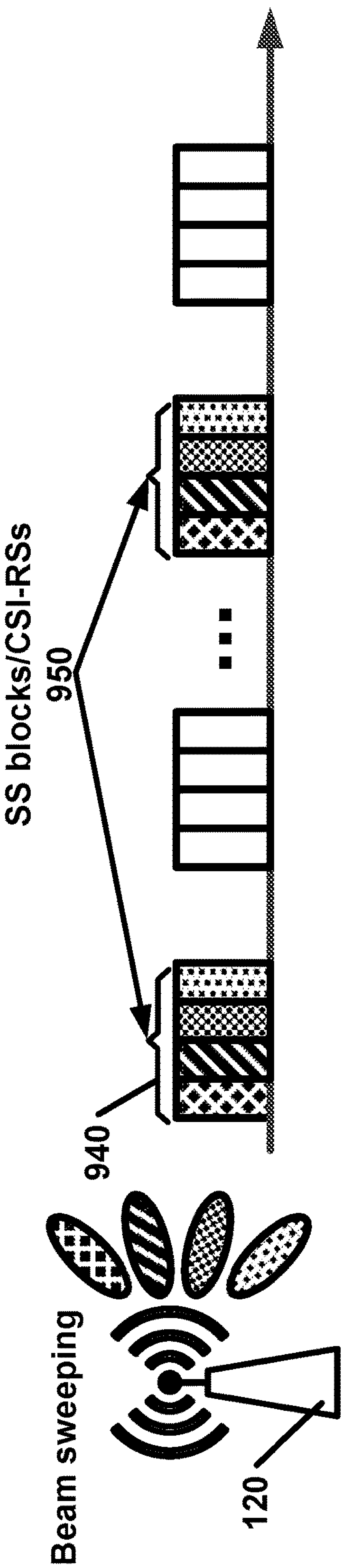
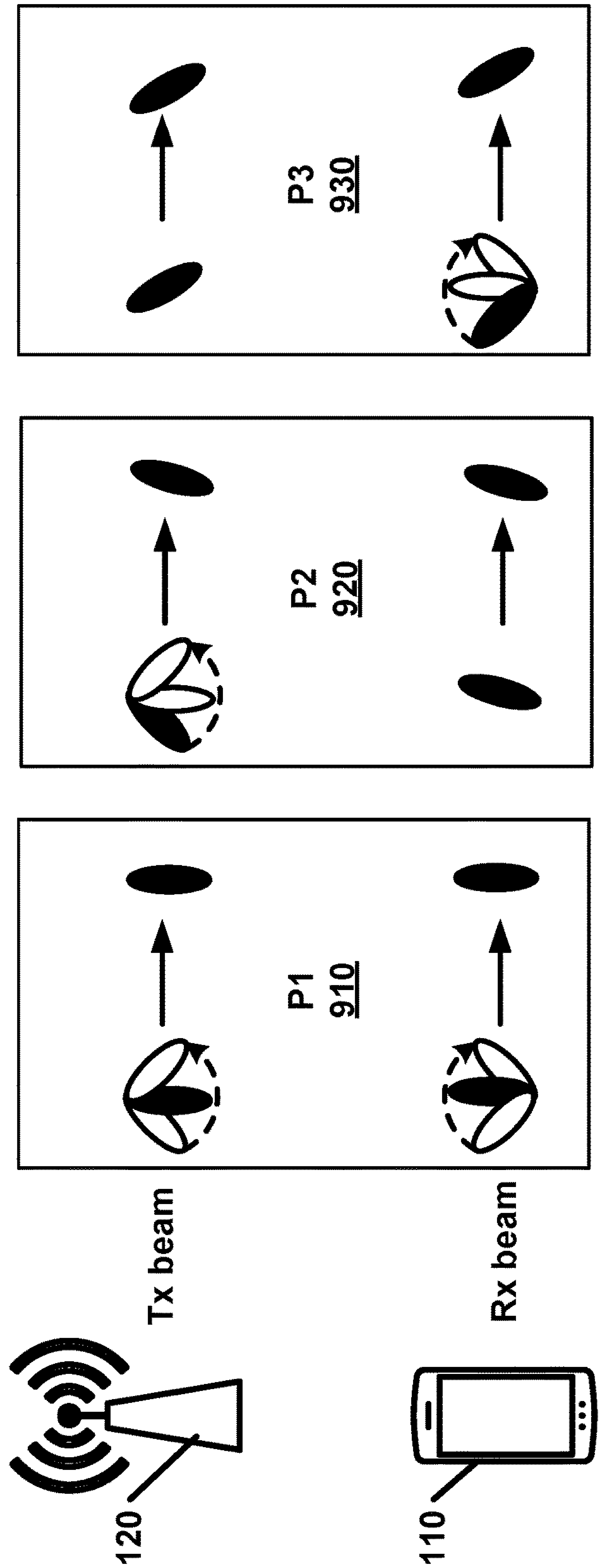


FIG. 8



SS blocks/CSI-RSs
950
940
Beam sweeping
120

FIG. 9A



P1
910
P2
920
P3
930
Tx beam
Rx beam
120
110

FIG. 9B

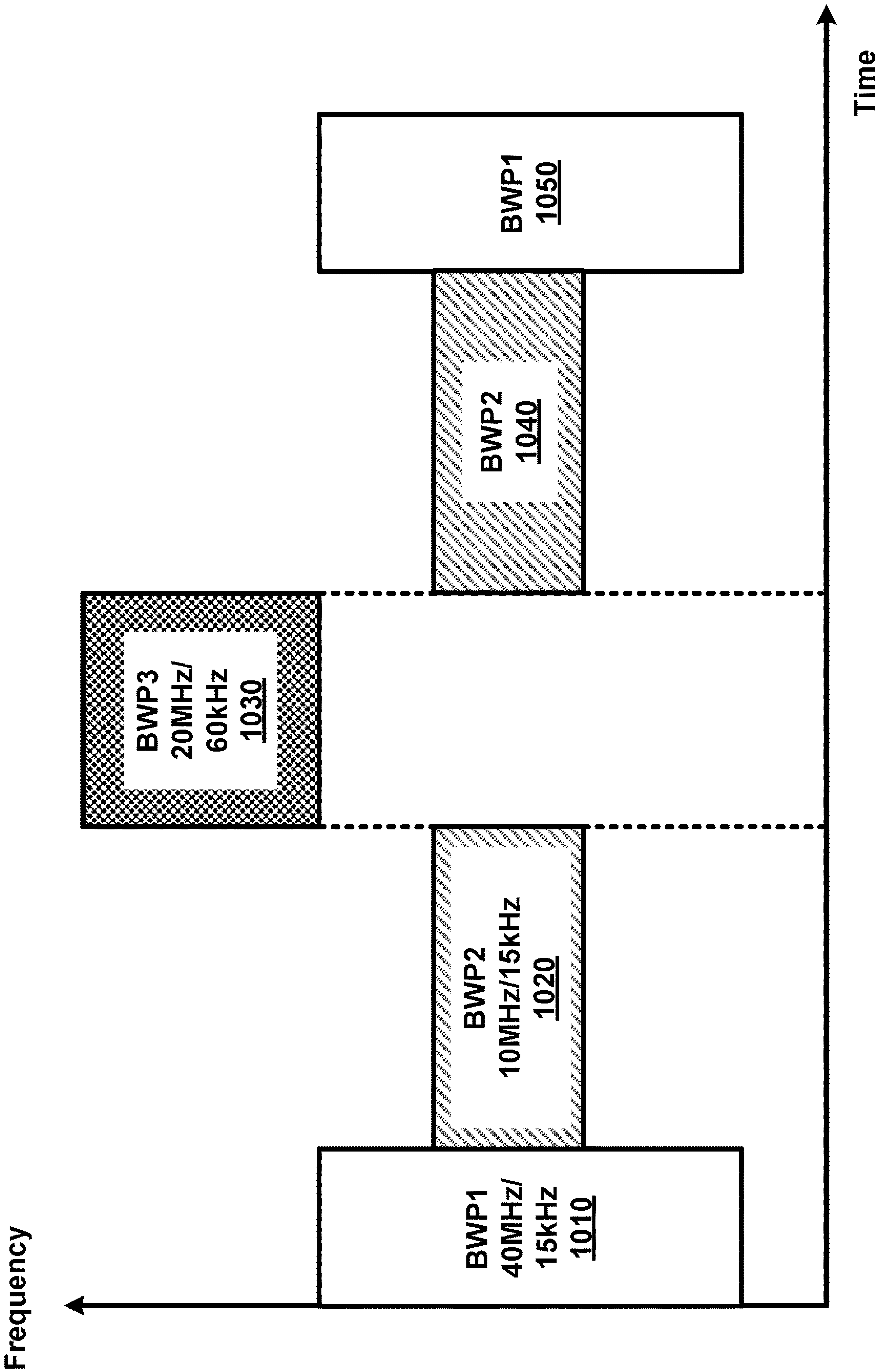

Time
Frequency
BWP1
40MHz/
15kHz
1010
BWP2
10MHz/15kHz
1020
BWP3
20MHz/
60kHz
1030
BWP2
1040
BWP1
1050

FIG. 10

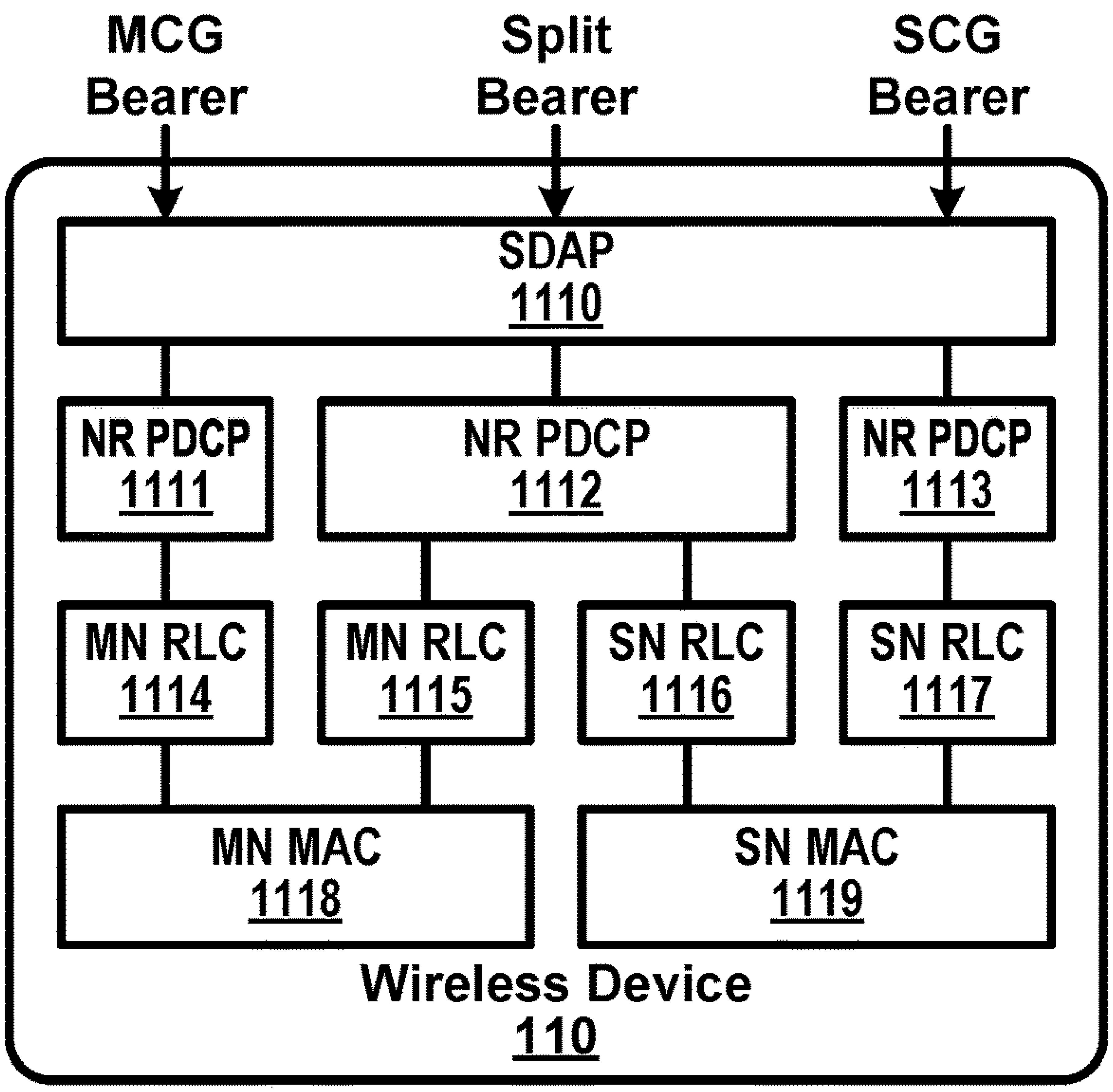


FIG. 11A

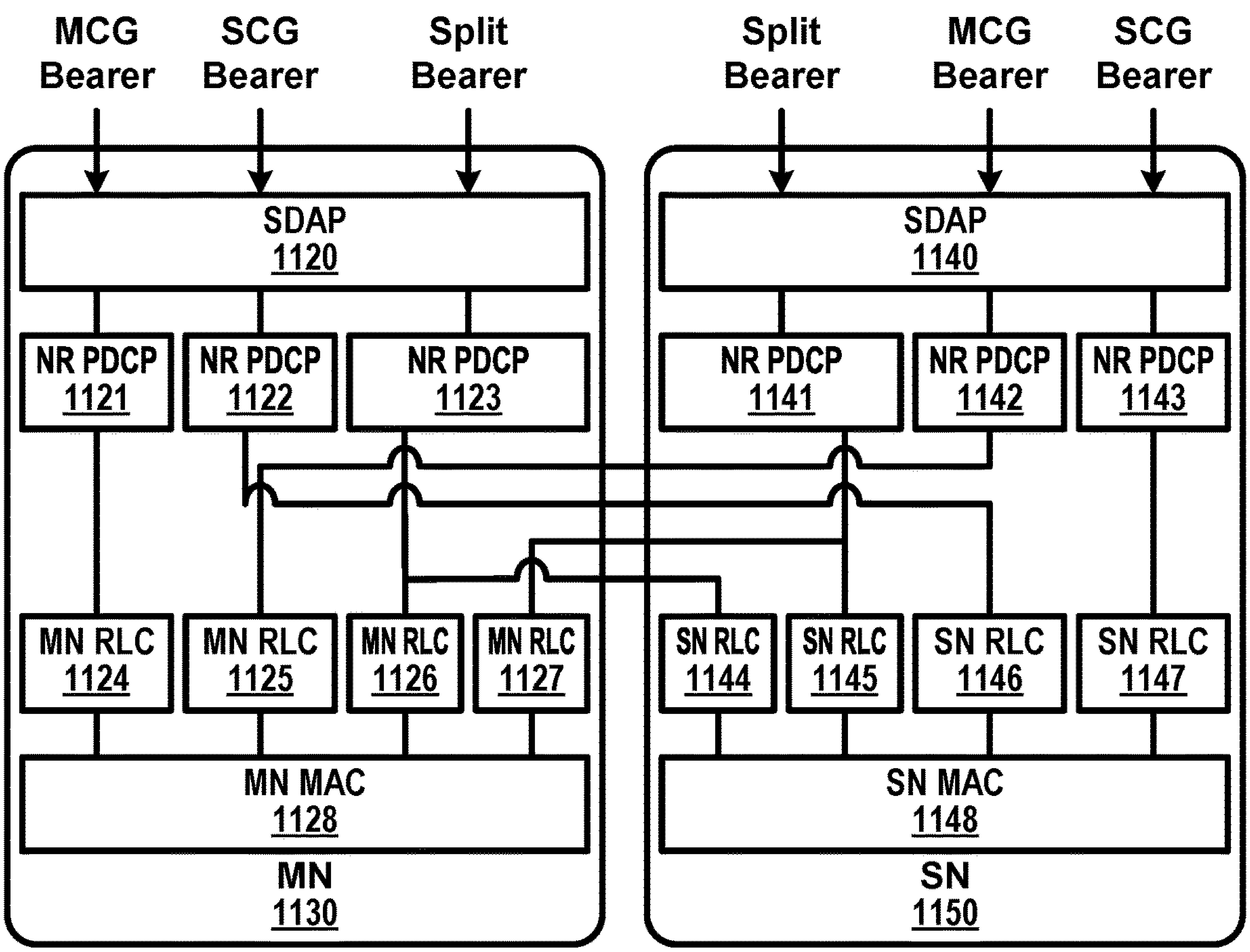


FIG. 11B

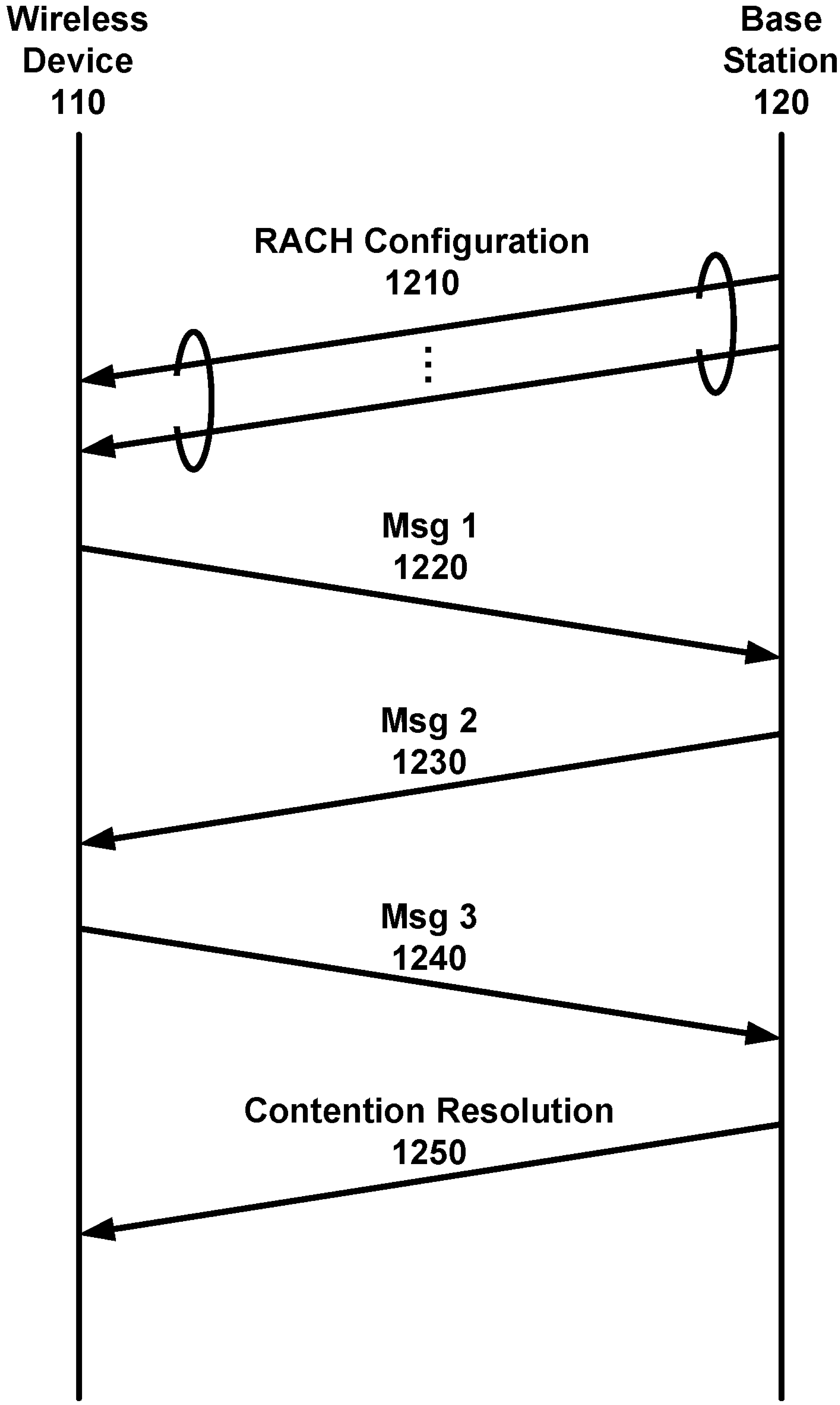

Wireless Device 110
Base Station 120
RACH Configuration 1210
Msg 1 1220
Msg 2 1230
Msg 3 1240
Contention Resolution 1250

FIG. 12

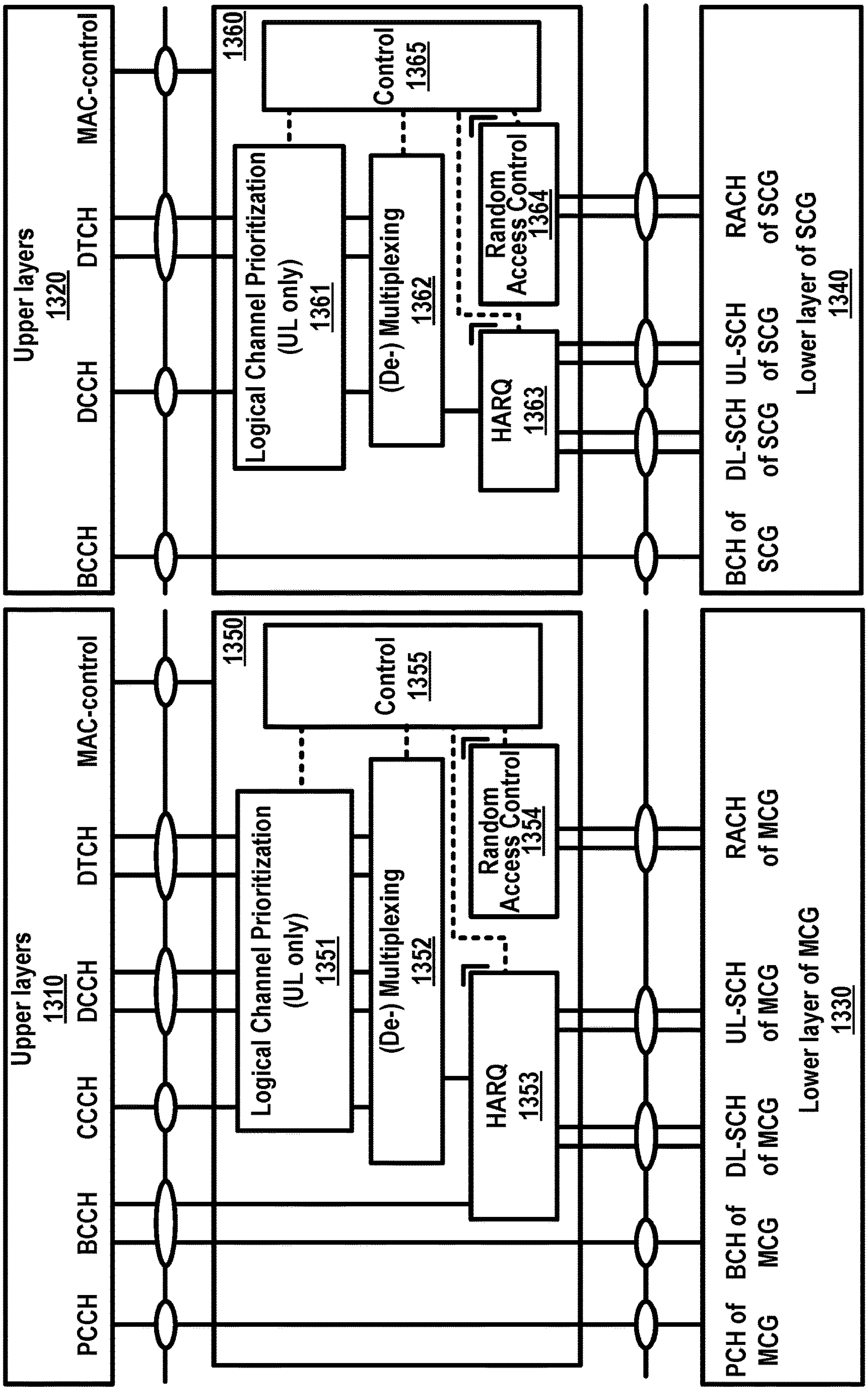

Upper layers 1320
MAC-control
DTCH
DCCH
BCCH
1360
Control 1365
Logical Channel Prioritization (UL only) 1361
(De-) Multiplexing 1362
Random Access Control 1364
HARQ 1363
RACH of SCG
UL-SCH of SCG
DL-SCH of SCG
BCH of SCG
Lower layer of SCG 1340
Upper layers 1310
MAC-control
DTCH
DCCH
CCCH
BCCH
PCCH
1350
Control 1355
Logical Channel Prioritization (UL only) 1351
(De-) Multiplexing 1352
Random Access Control 1354
HARQ 1353
RACH of MCG
UL-SCH of MCG
DL-SCH of MCG
BCH of MCG
PCH of MCG
Lower layer of MCG 1330

FIG. 13

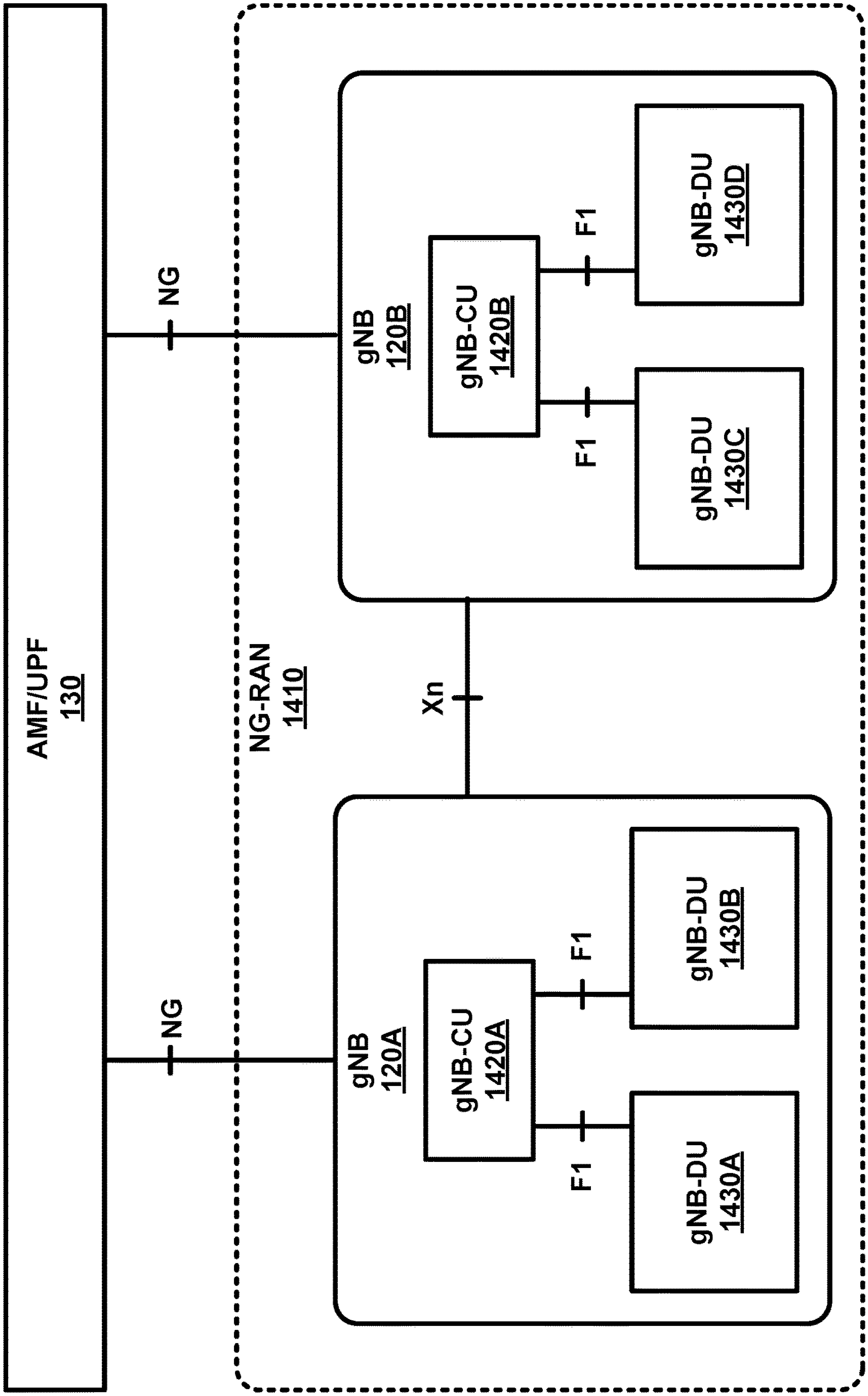

AMF/UPF
130
NG
NG
NG-RAN
1410
gNB
120B
gNB-CU
1420B
F1
F1
gNB-DU
1430D
gNB-DU
1430C
Xn
gNB
120A
gNB-CU
1420A
F1
F1
gNB-DU
1430B
gNB-DU
1430A

FIG. 14

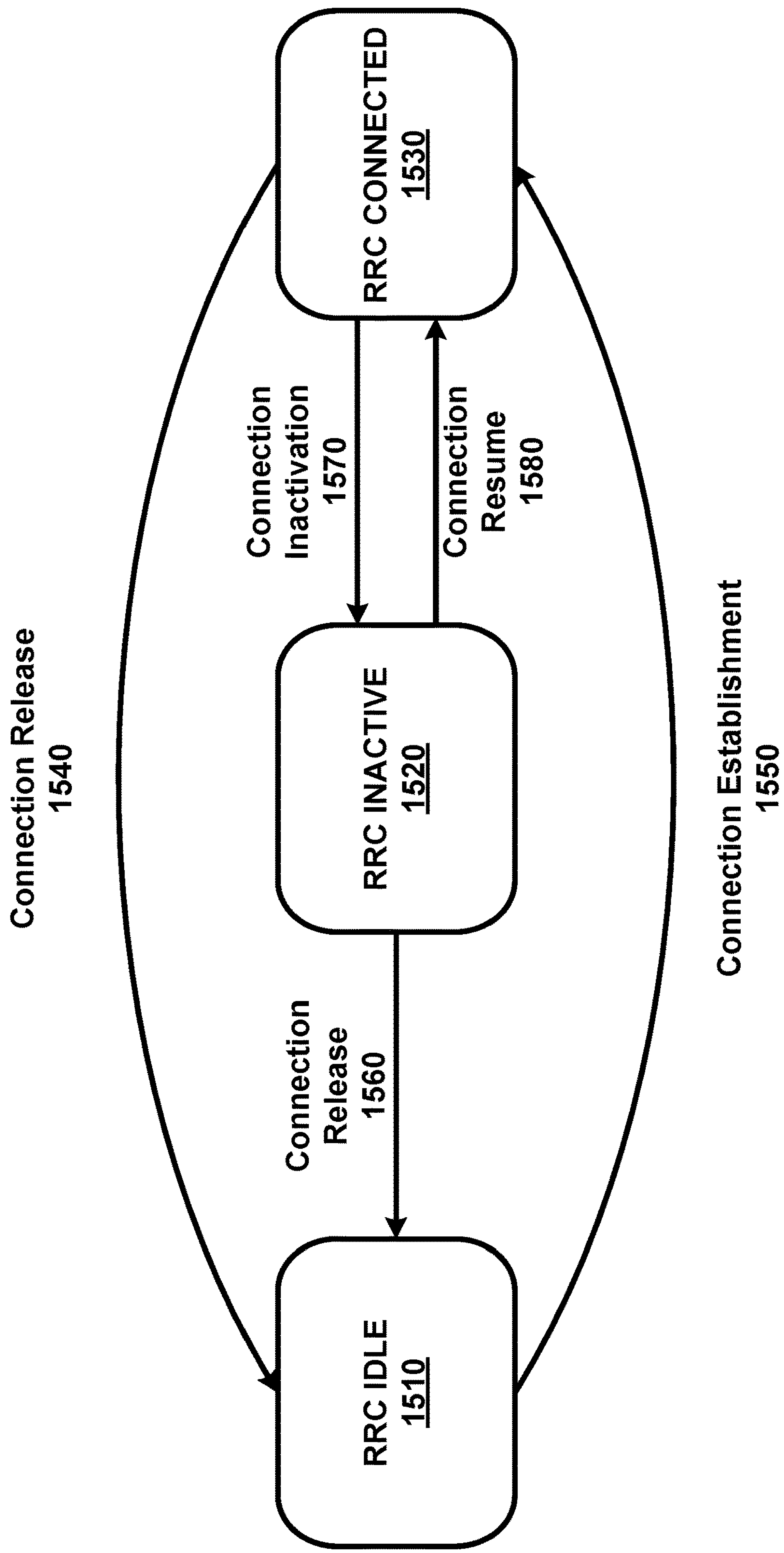

RRC CONNECTED 1530
Connection Inactivation 1570
Connection Resume 1580
Connection Release 1540
RRC INACTIVE 1520
Connection Establishment 1550
Connection Release 1560
RRC IDLE 1510

FIG. 15

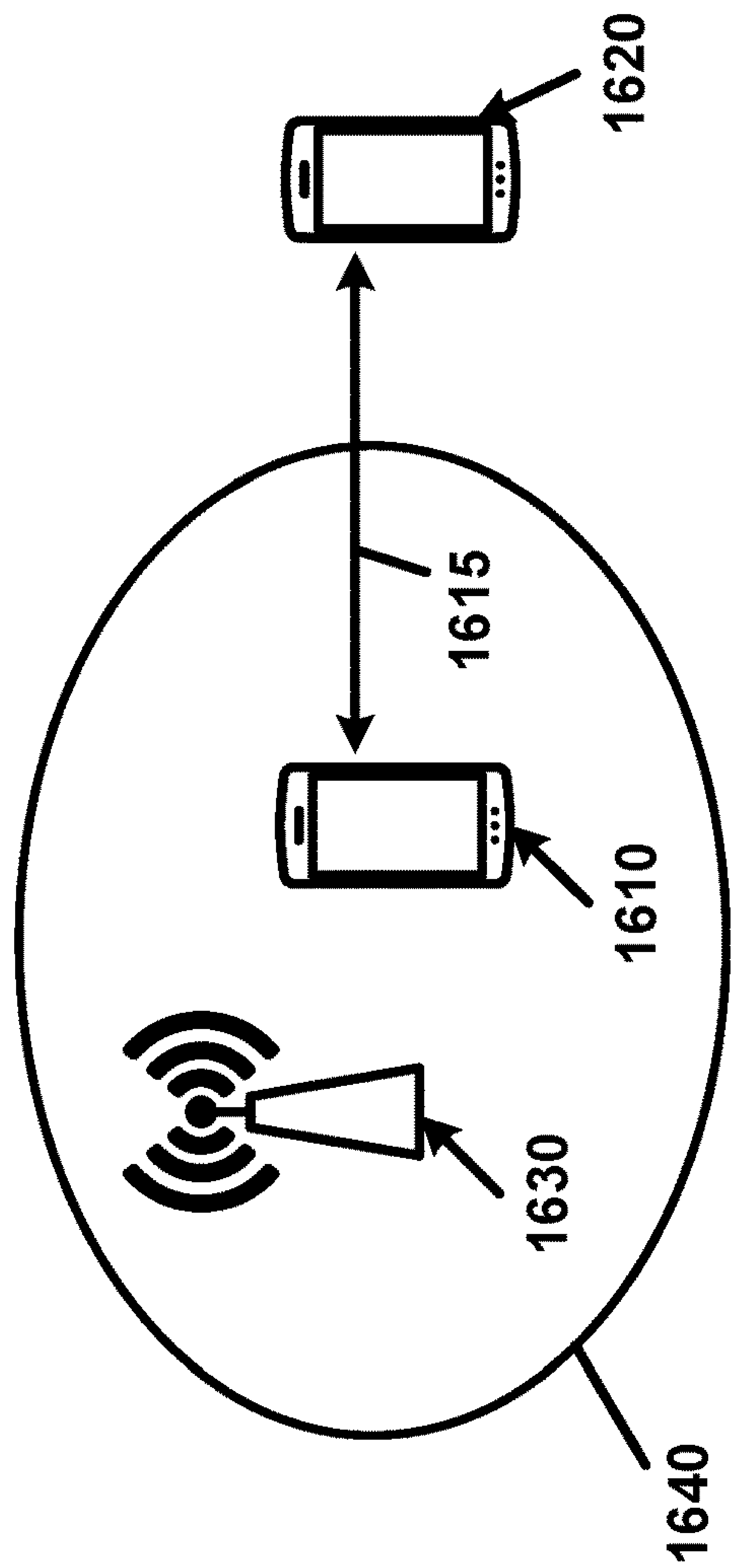


FIG. 16B

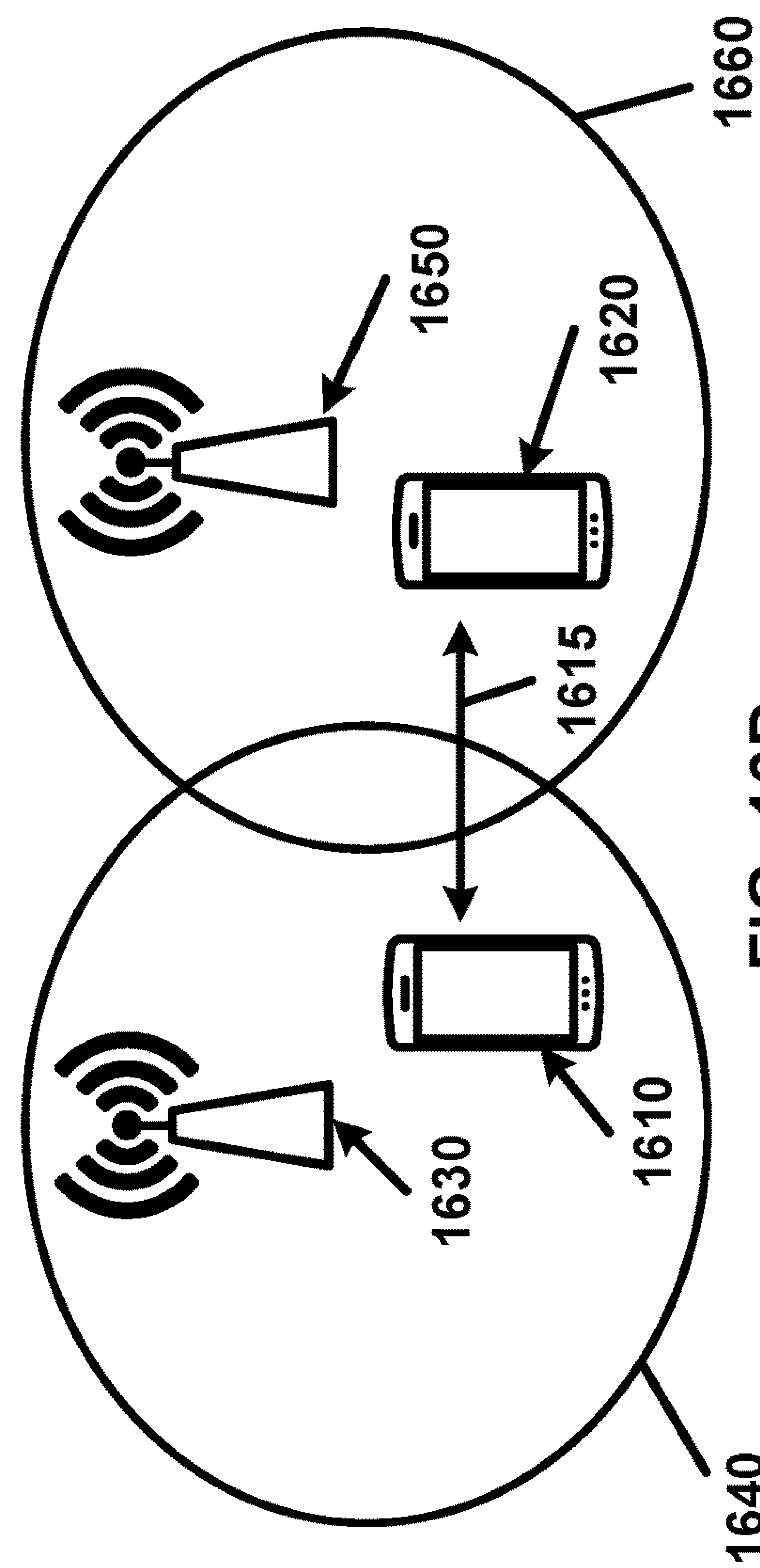


FIG. 16D

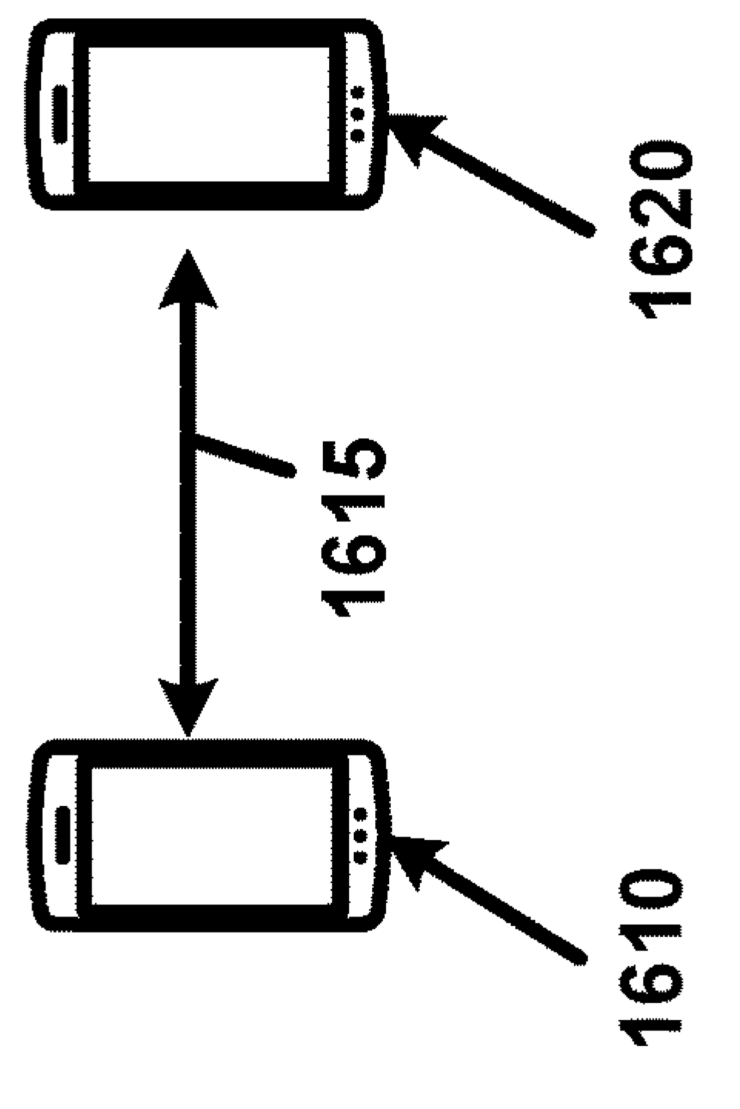


FIG. 16A

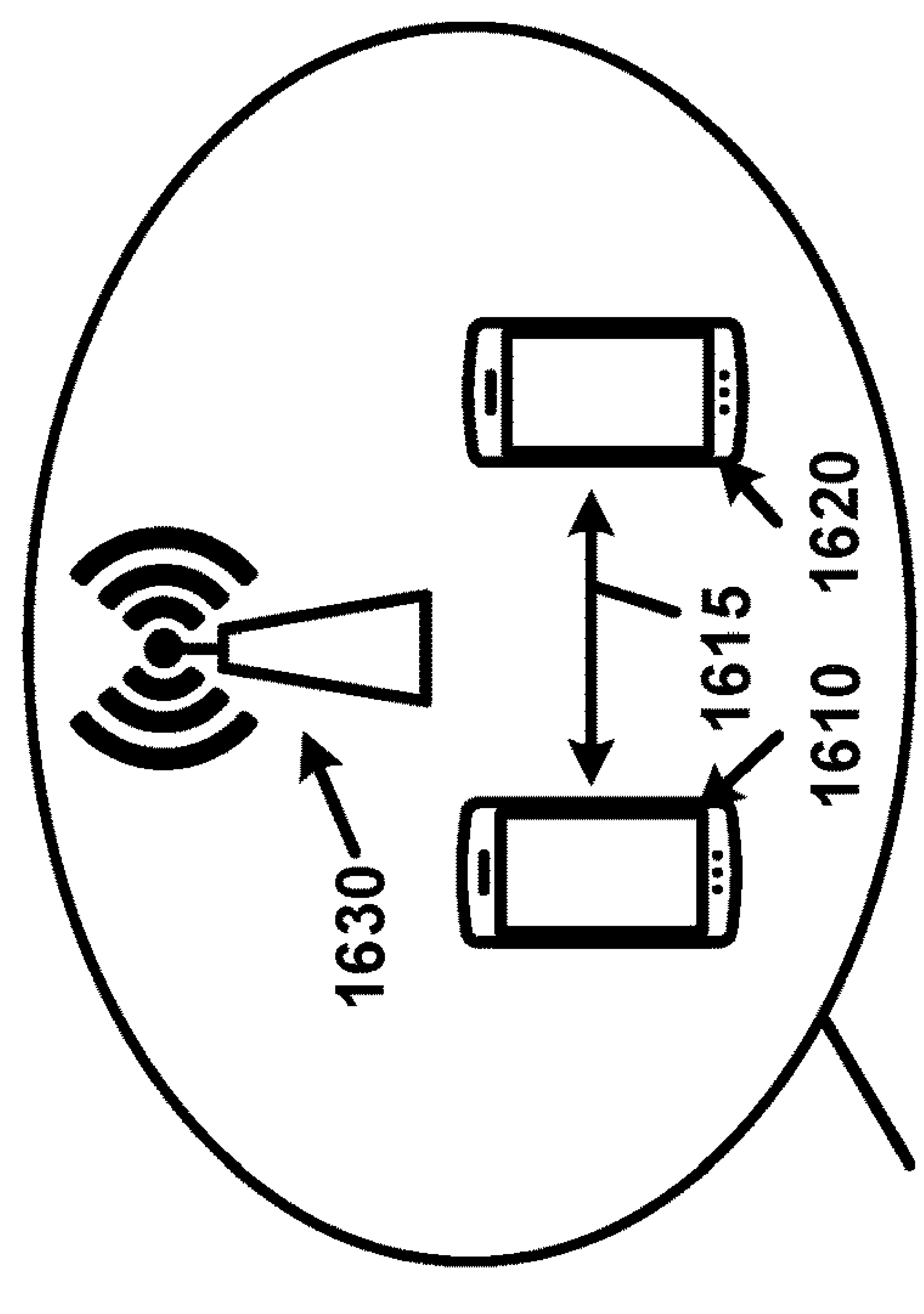


FIG. 16C

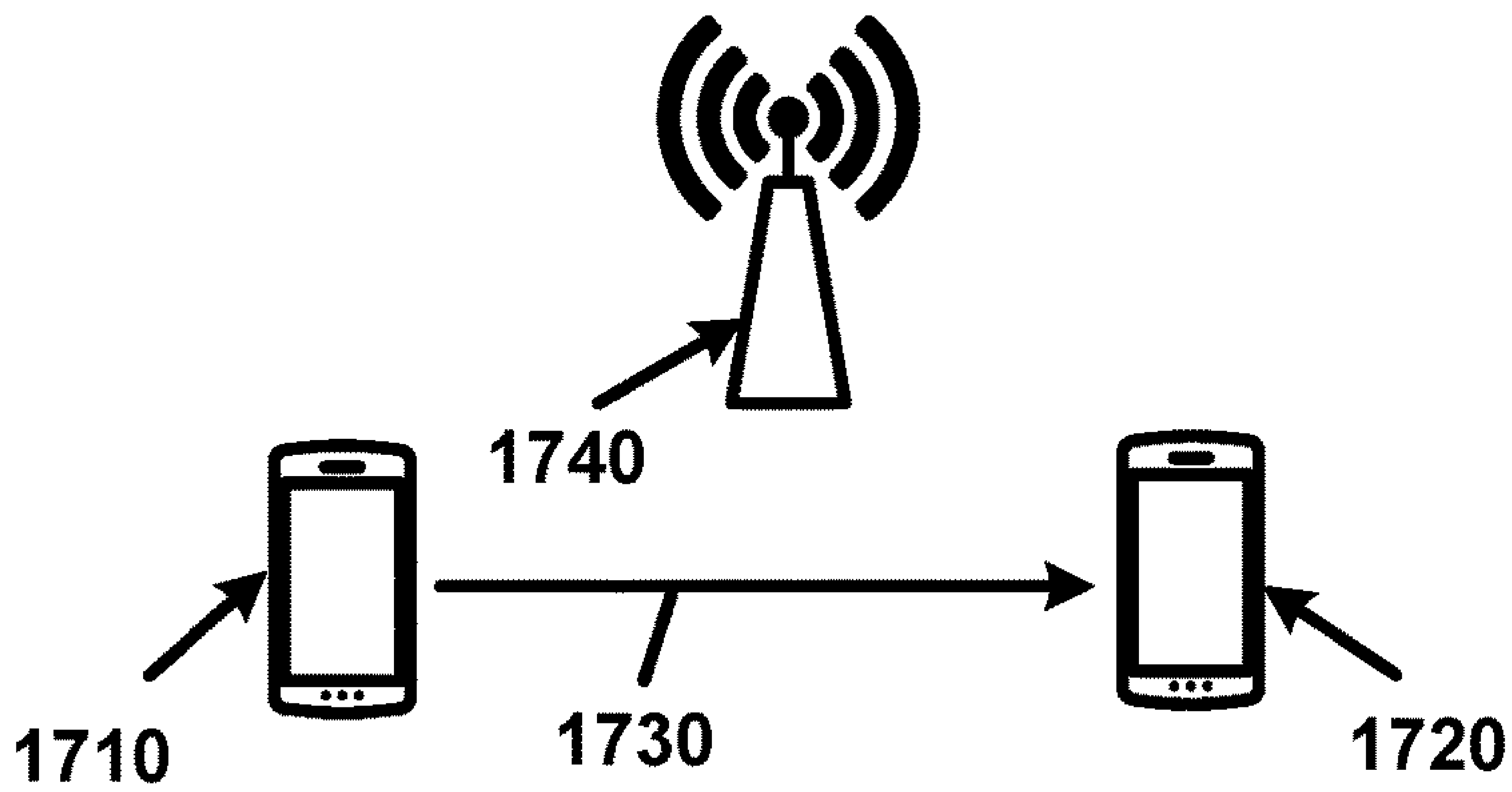


FIG. 17A

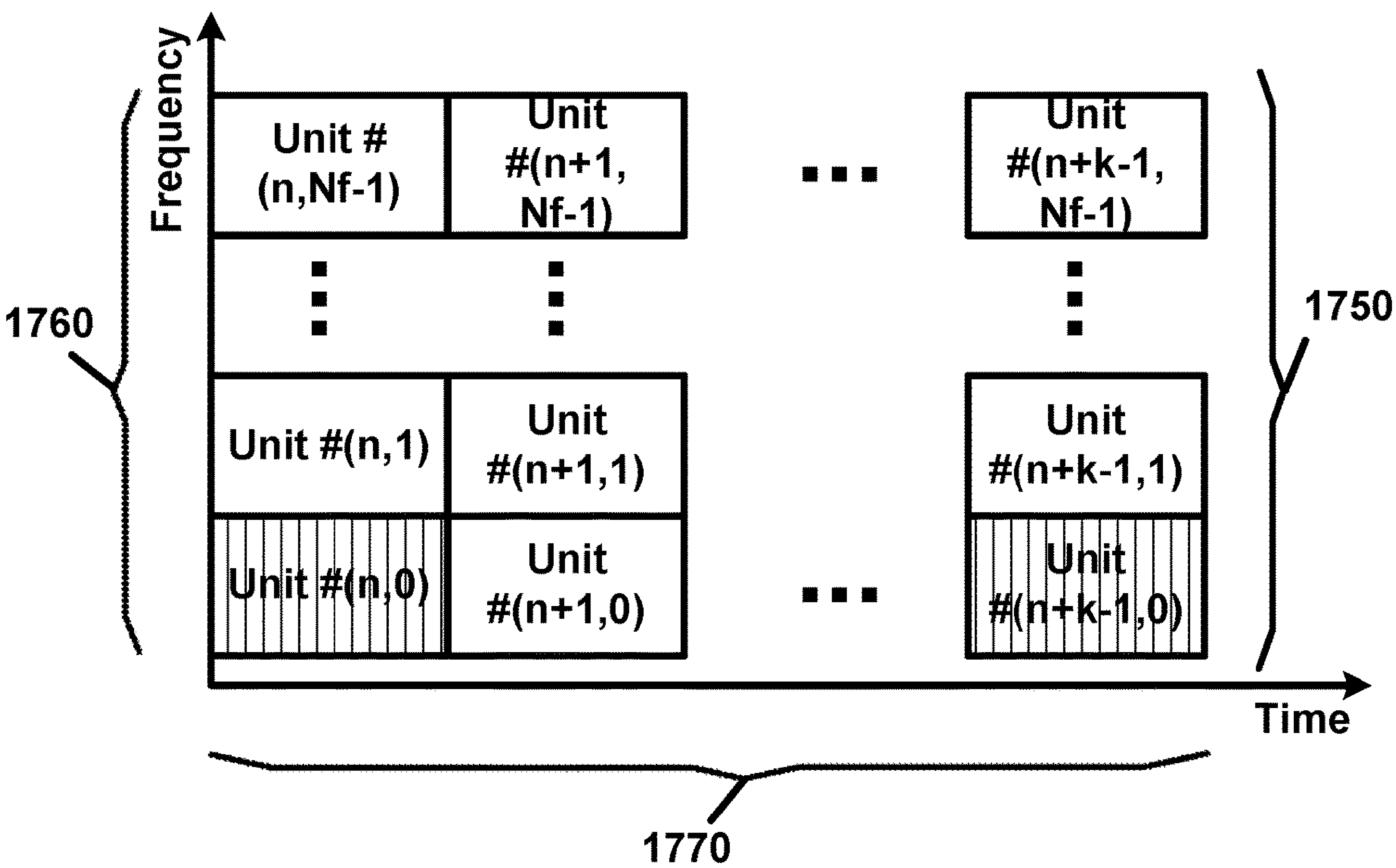


FIG. 17B

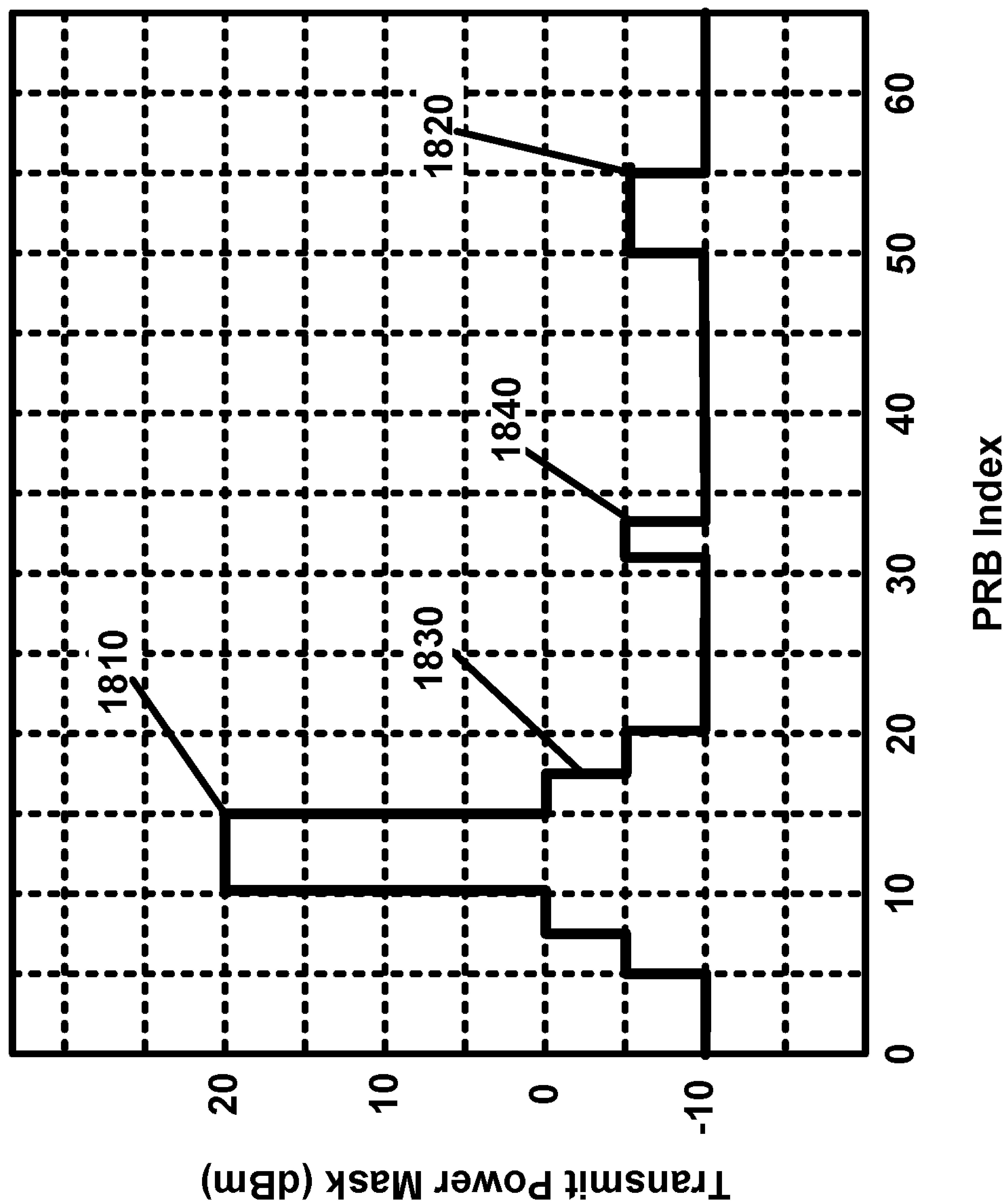

1810
1830
1840
1820
Transmit Power Mask (dBm)
20
10
0
-10
0
10
20
30
40
50
60
PRB Index

FIG. 18

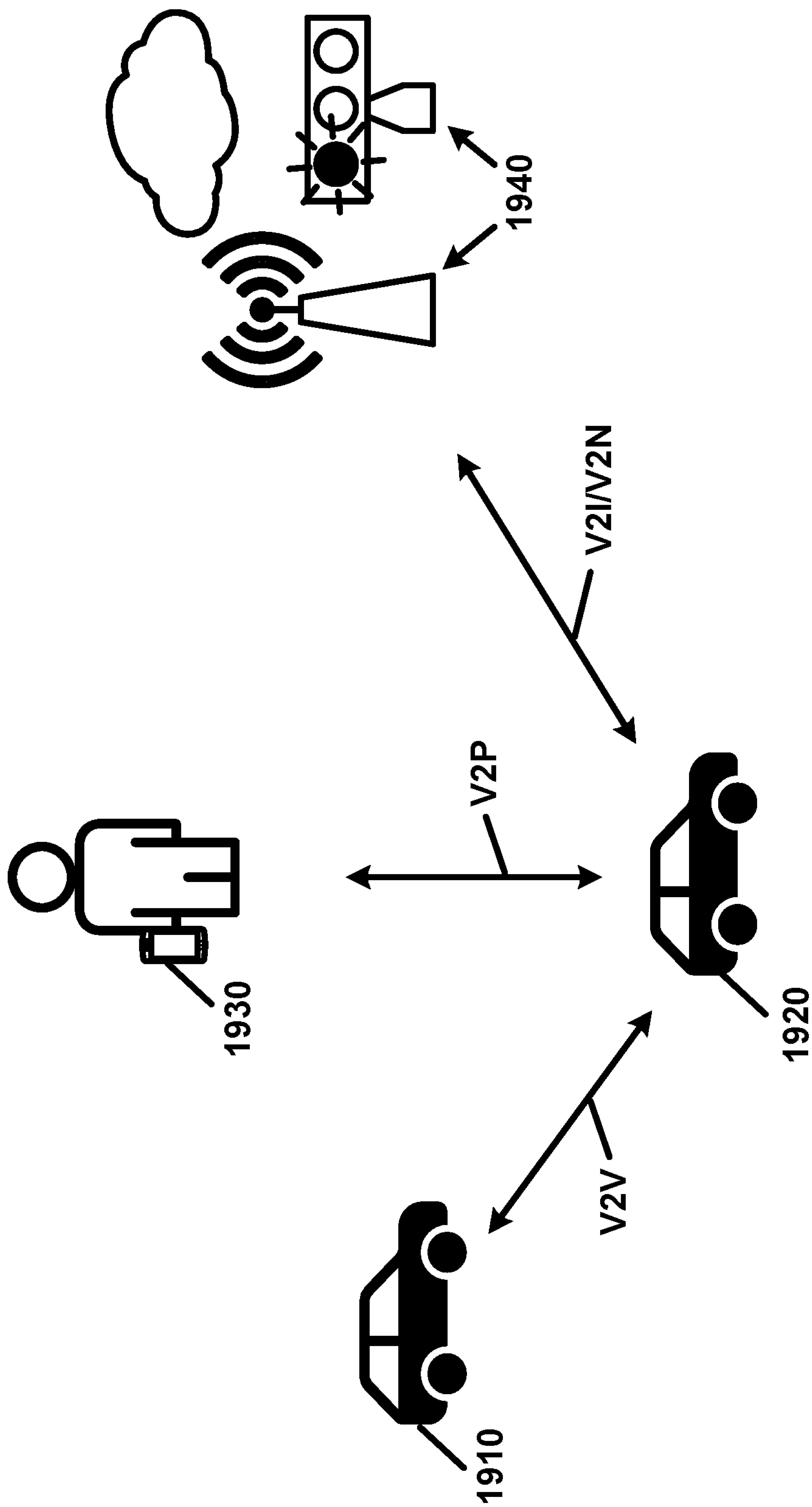


FIG. 19

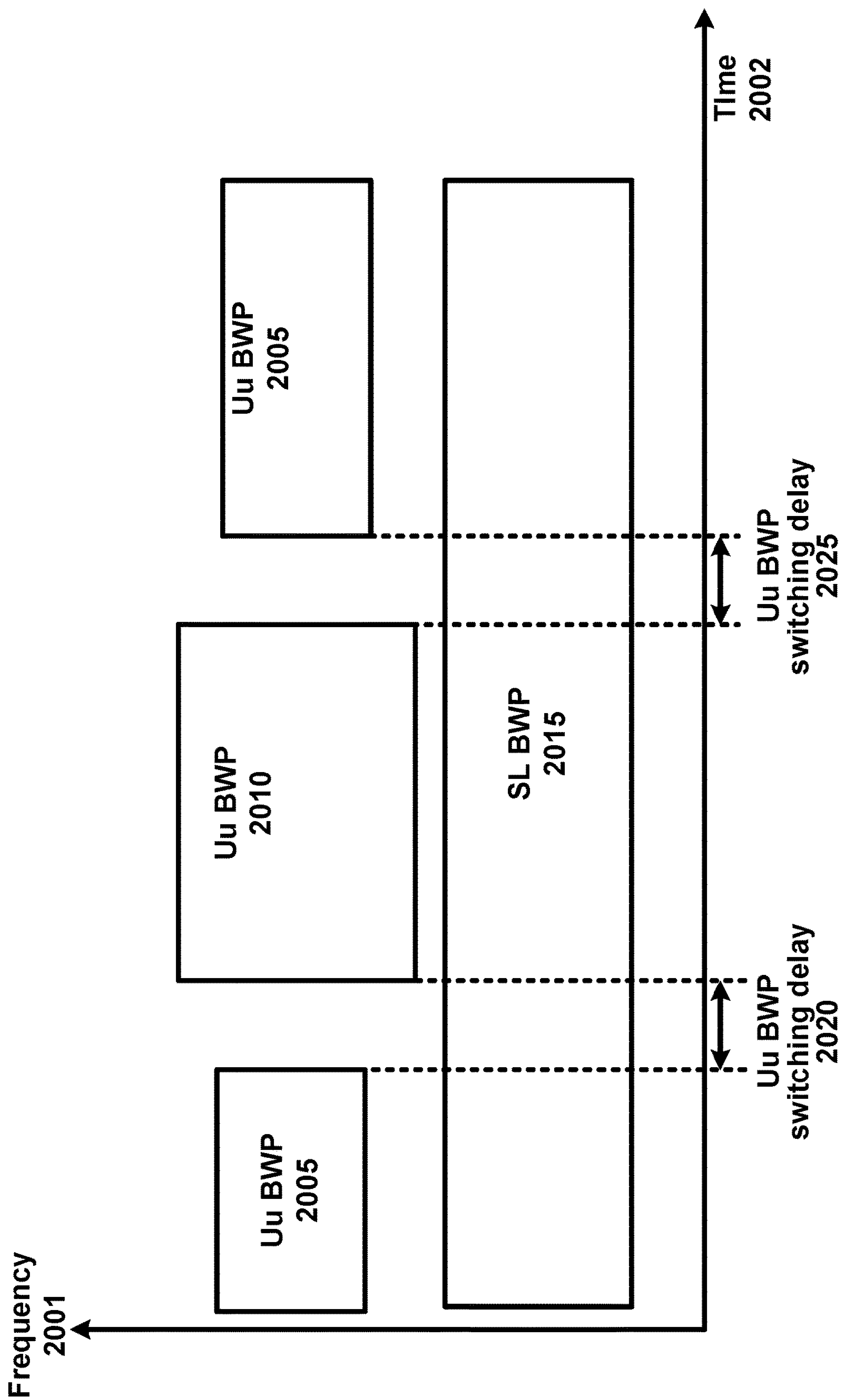

Time
2002
Frequency
2001
Uu BWP
2005
Uu BWP
2010
Uu BWP
2005
SL BWP
2015
Uu BWP
switching delay
2025
Uu BWP
switching delay
2020

FIG. 20A

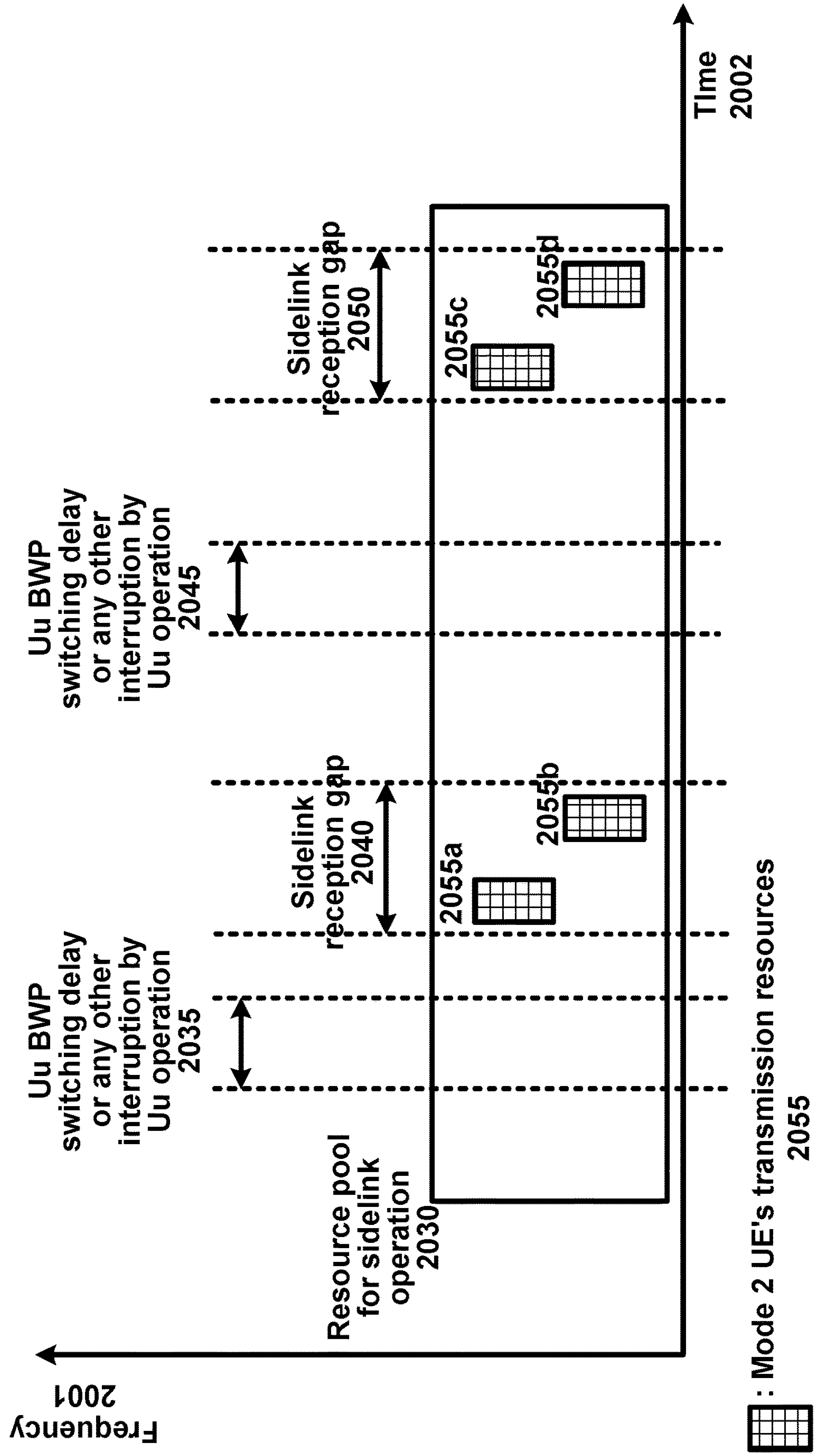

Time
2002
Frequency
2001
Resource pool
for sidelink
operation
2030
Uu BWP
switching delay
or any other
interruption by
Uu operation
2035
Sidelink
reception gap
2040
2055a
2055b
Uu BWP
switching delay
or any other
interruption by
Uu operation
2045
Sidelink
reception gap
2050
2055c
2055d
: Mode 2 UE's transmission resources
2055

FIG. 20B

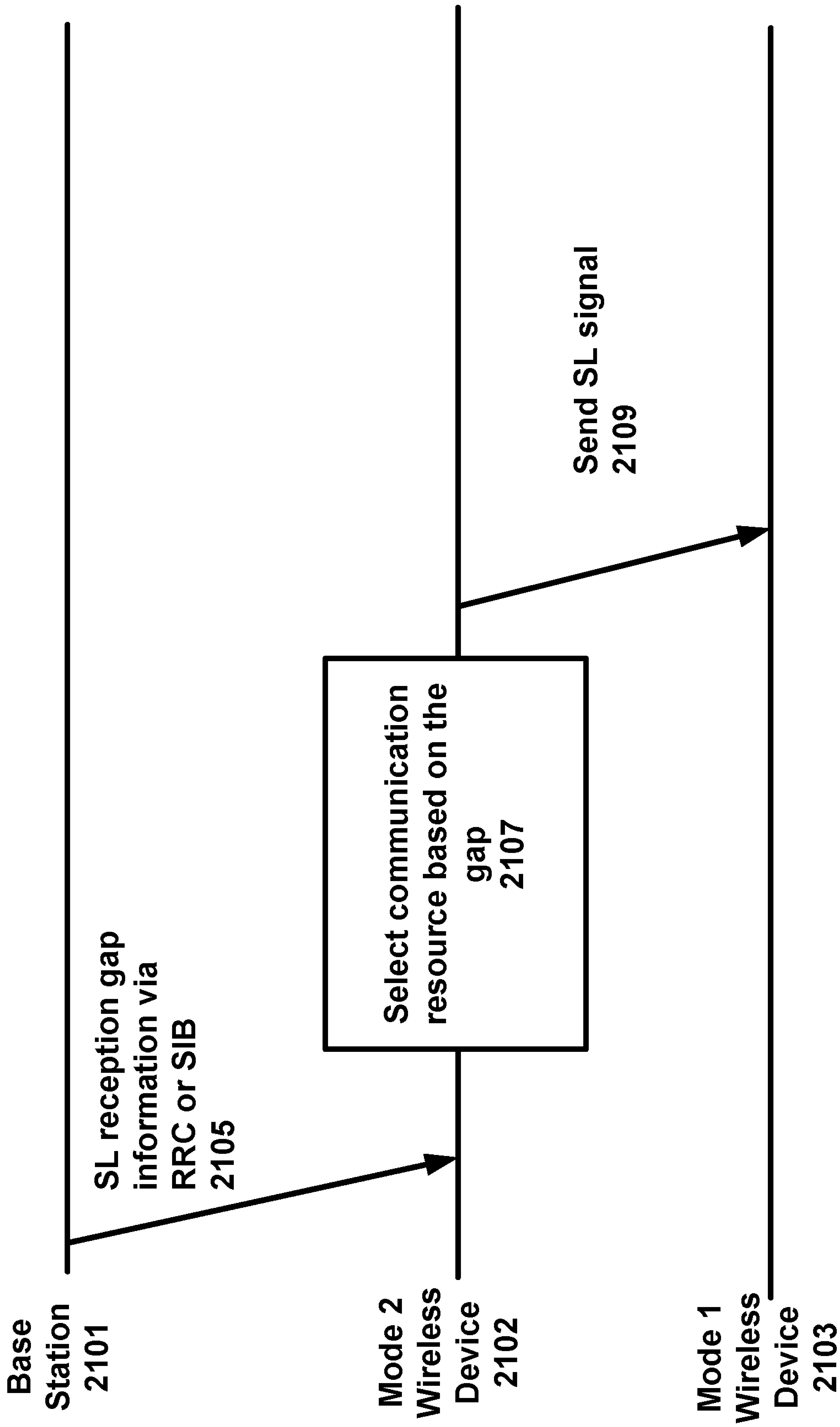

Base Station 2101
Mode 2 Wireless Device 2102
Mode 1 Wireless Device 2103
SL reception gap information via RRC or SIB 2105
Select communication resource based on the gap 2107
Send SL signal 2109

FIG. 21

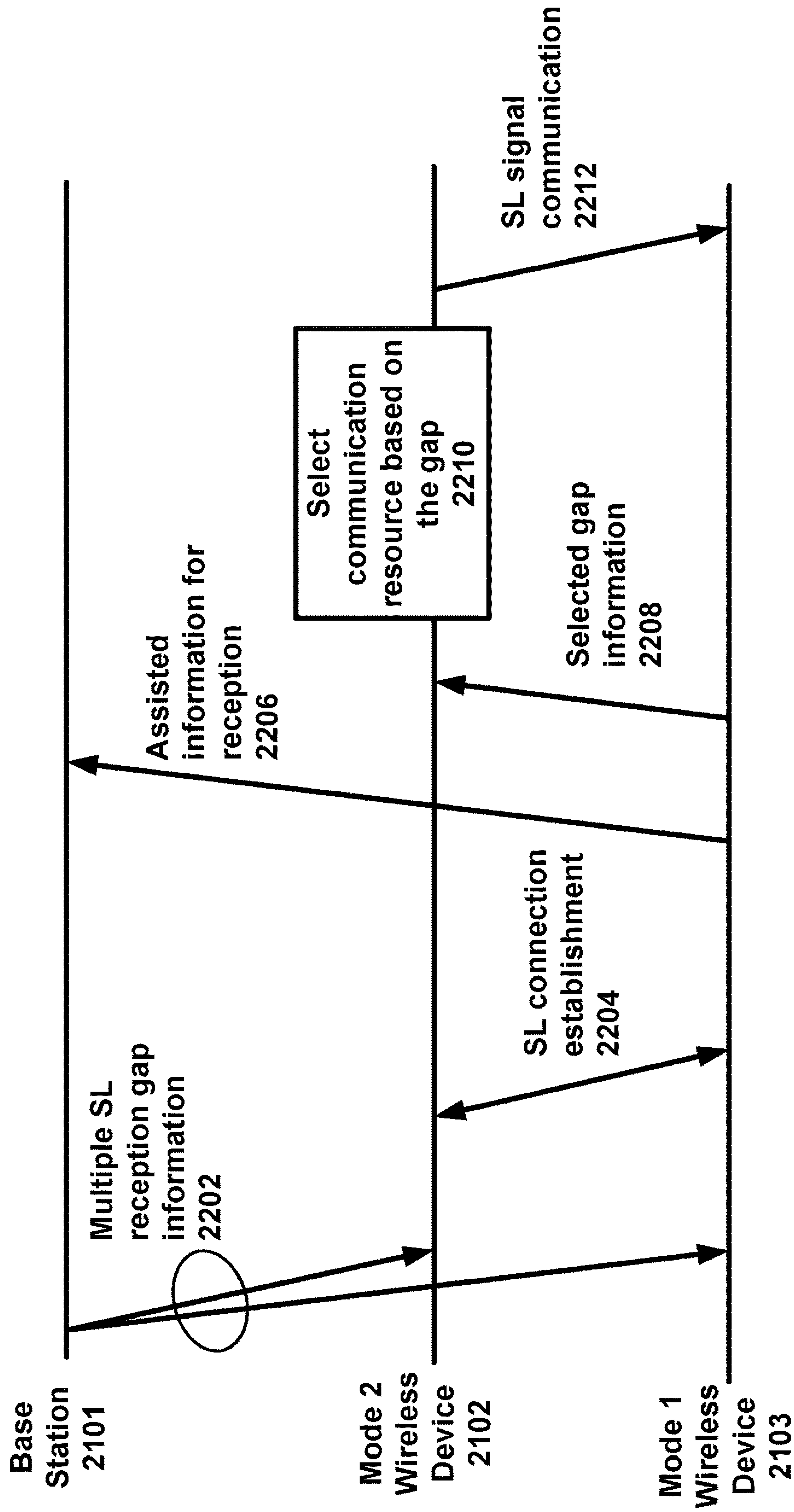

Base Station 2101
Mode 2 Wireless Device 2102
Mode 1 Wireless Device 2103
Multiple SL reception gap information 2202
SL connection establishment 2204
Assisted information for reception 2206
Selected gap information 2208
Select communication resource based on the gap 2210
SL signal communication 2212

FIG. 22

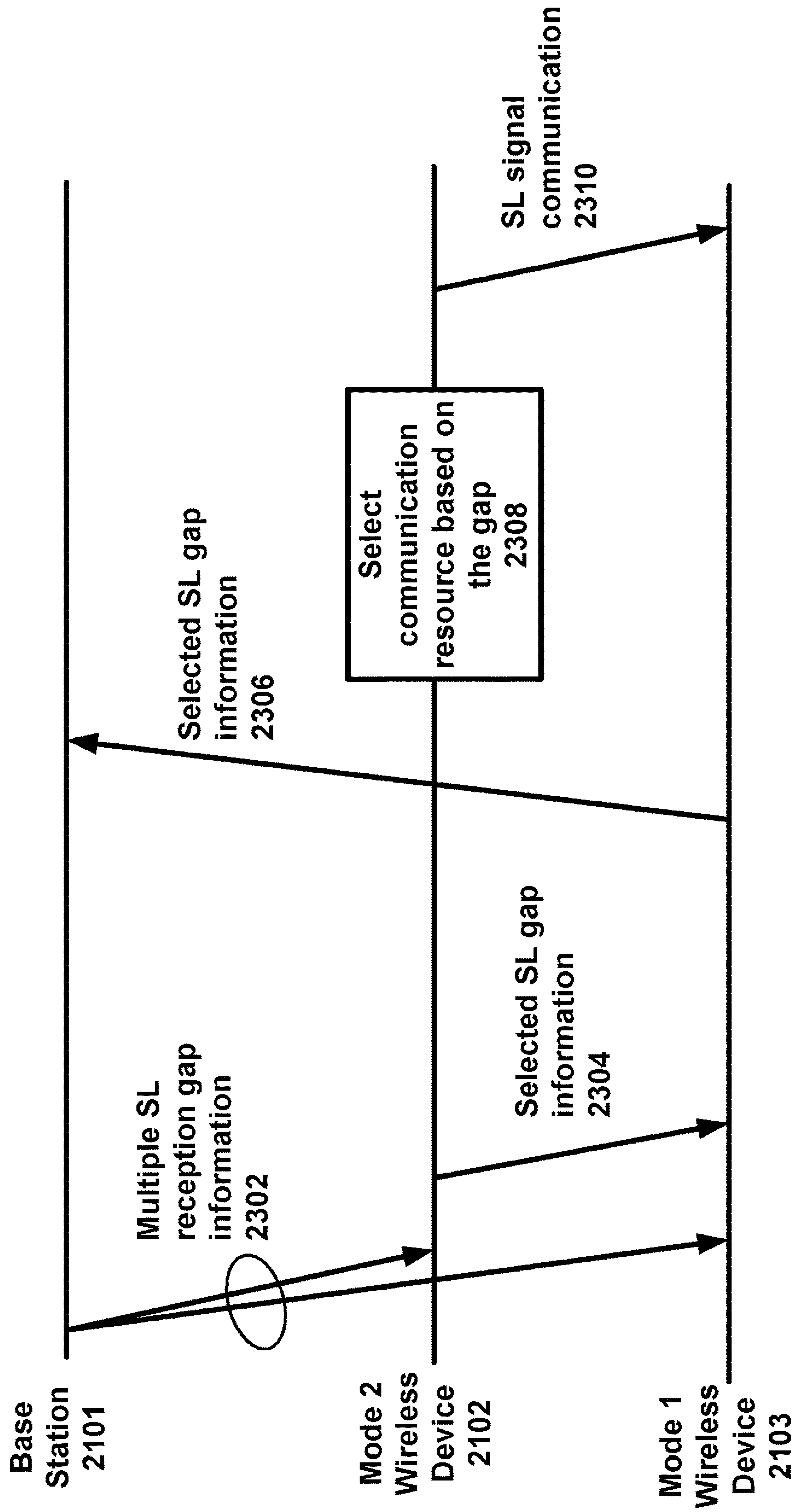

Base Station 2101
Mode 2 Wireless Device 2102
Mode 1 Wireless Device 2103
Multiple SL reception gap information 2302
Selected SL gap information 2304
Selected SL gap information 2306
Select communication resource based on the gap 2308
SL signal communication 2310

FIG. 23

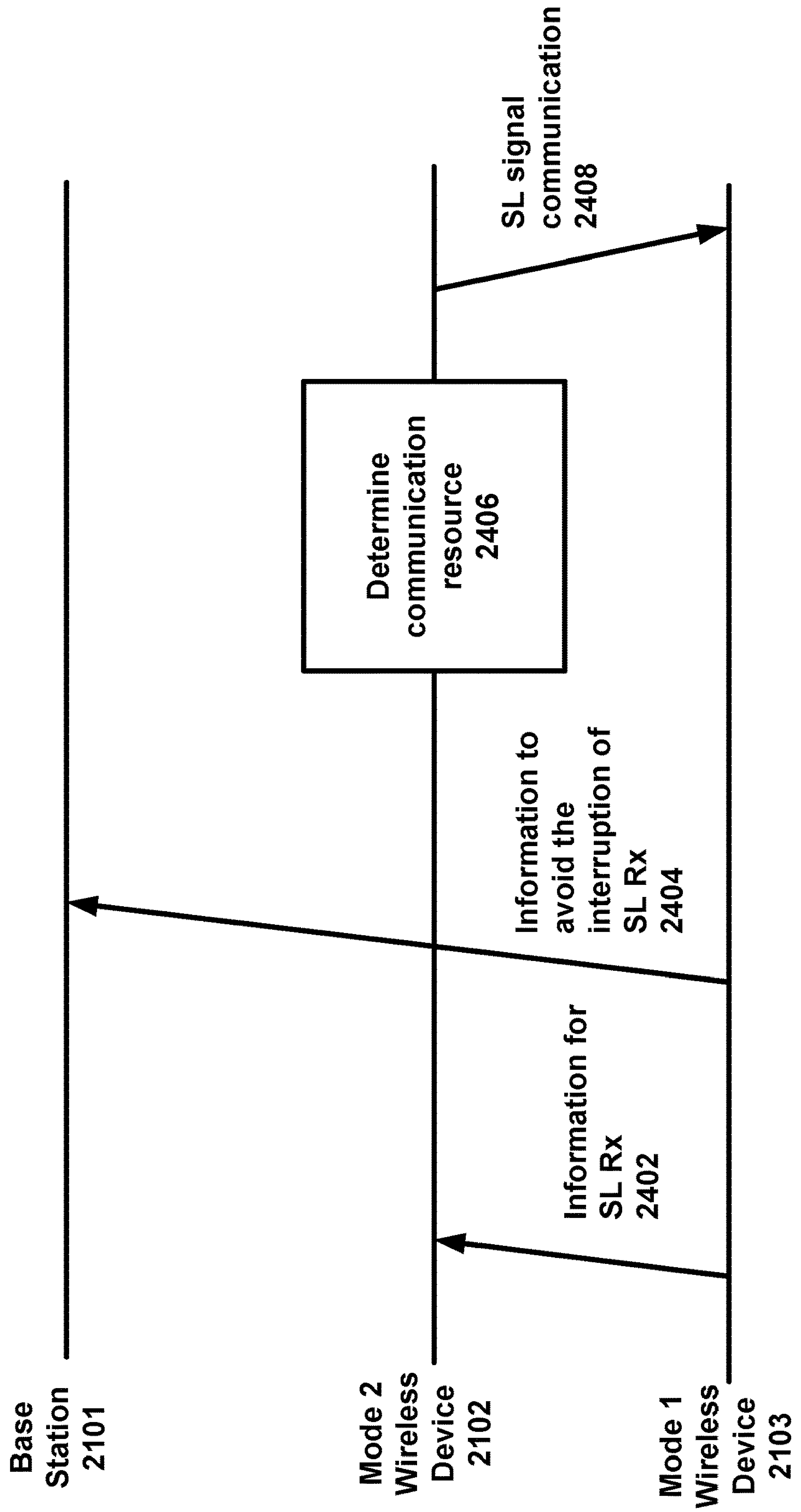

Base Station 2101
Mode 2 Wireless Device 2102
Mode 1 Wireless Device 2103
Information for SL Rx 2402
Information to avoid the interruption of SL Rx 2404
Determine communication resource 2406
SL signal communication 2408

FIG. 24

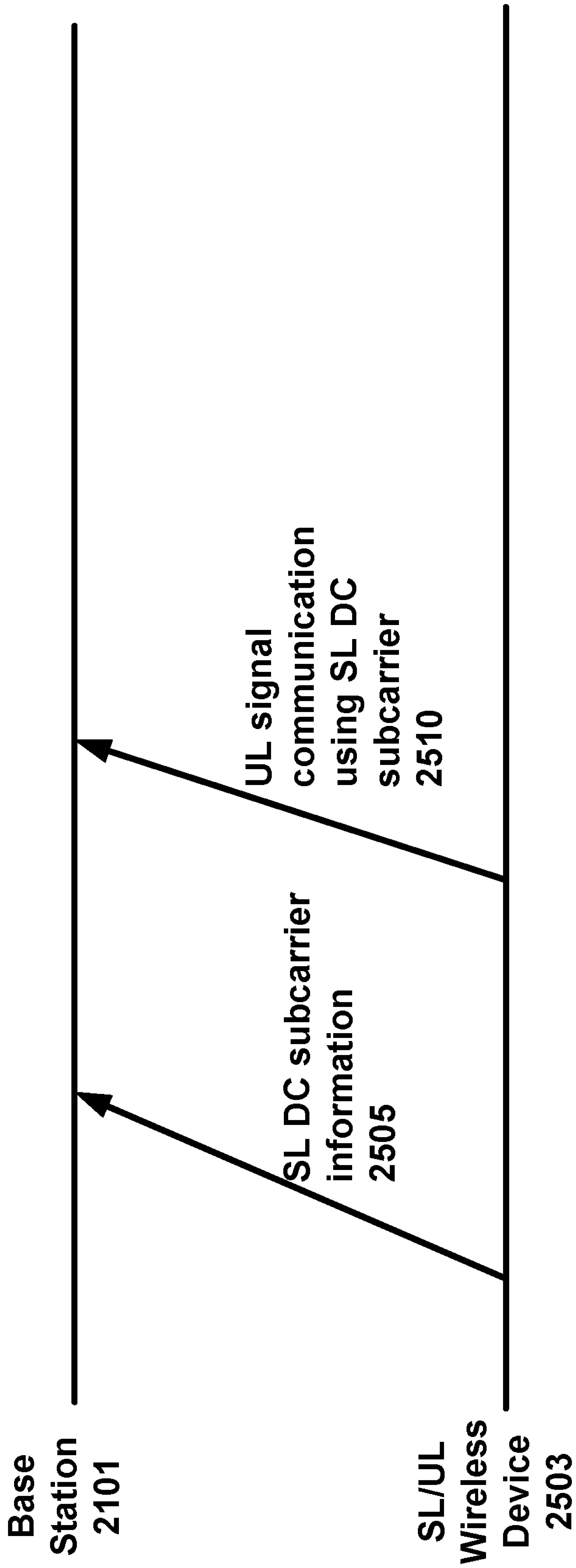

Base Station 2101
SL/UL Wireless Device 2503
SL DC subcarrier information 2505
UL signal communication using SL DC subcarrier 2510

FIG. 25A

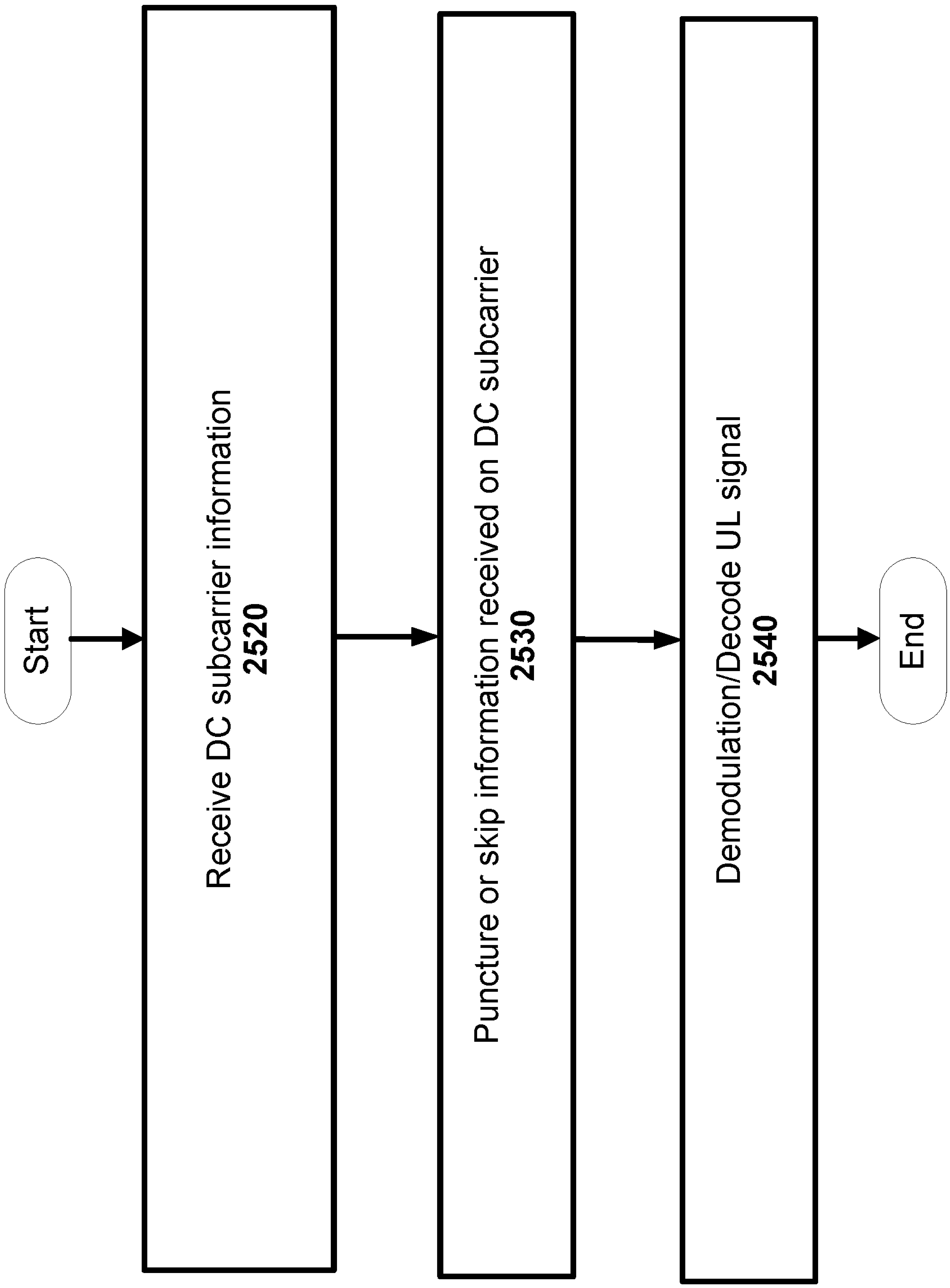

Start
Receive DC subcarrier information
2520
Puncture or skip information received on DC subcarrier
2530
Demodulation/Decode UL signal
2540
End

FIG. 25B

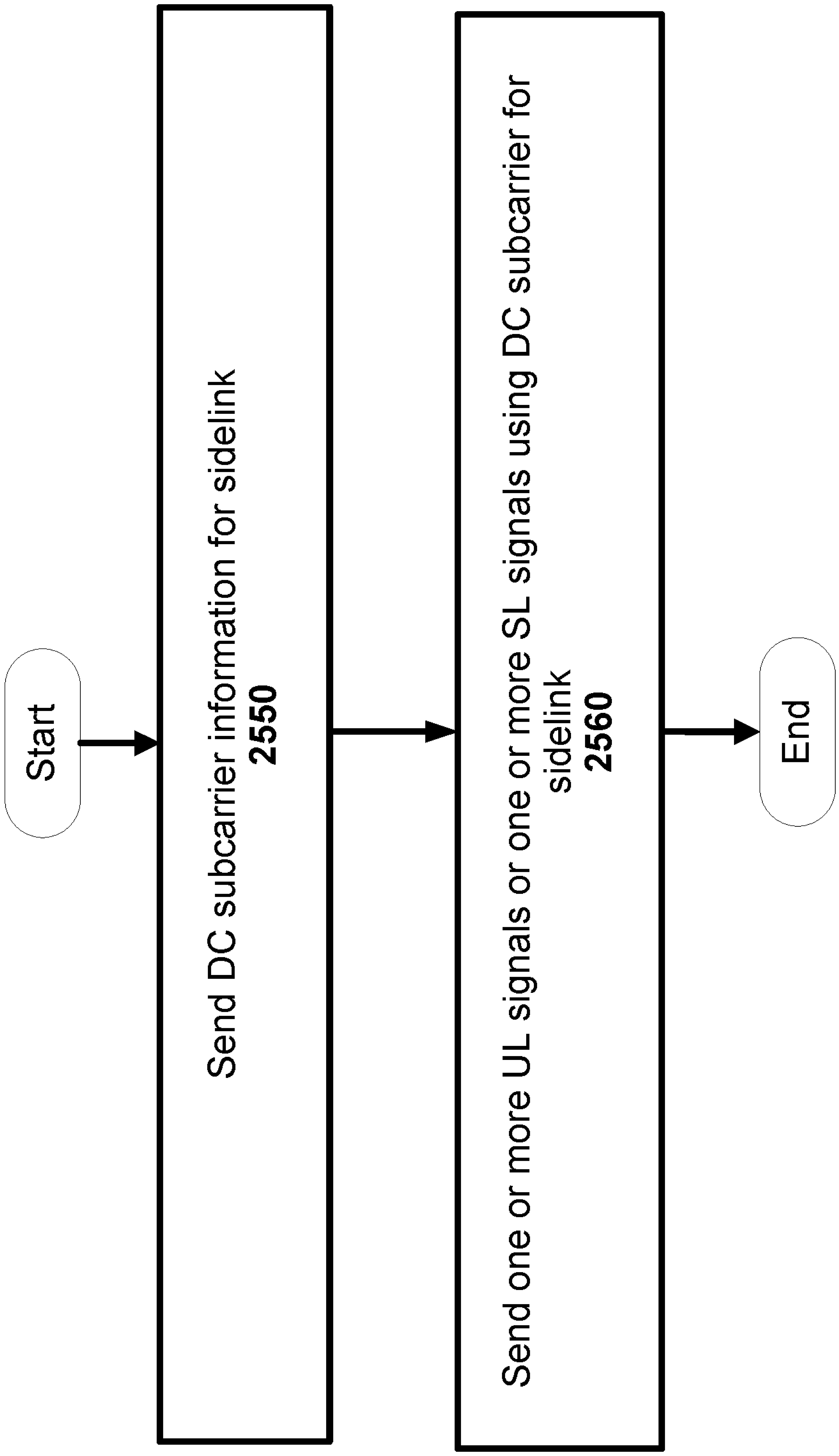

Start
Send DC subcarrier information for sidelink
2550
Send one or more UL signals or one or more SL signals using DC subcarrier for sidelink
2560
End

FIG. 25C

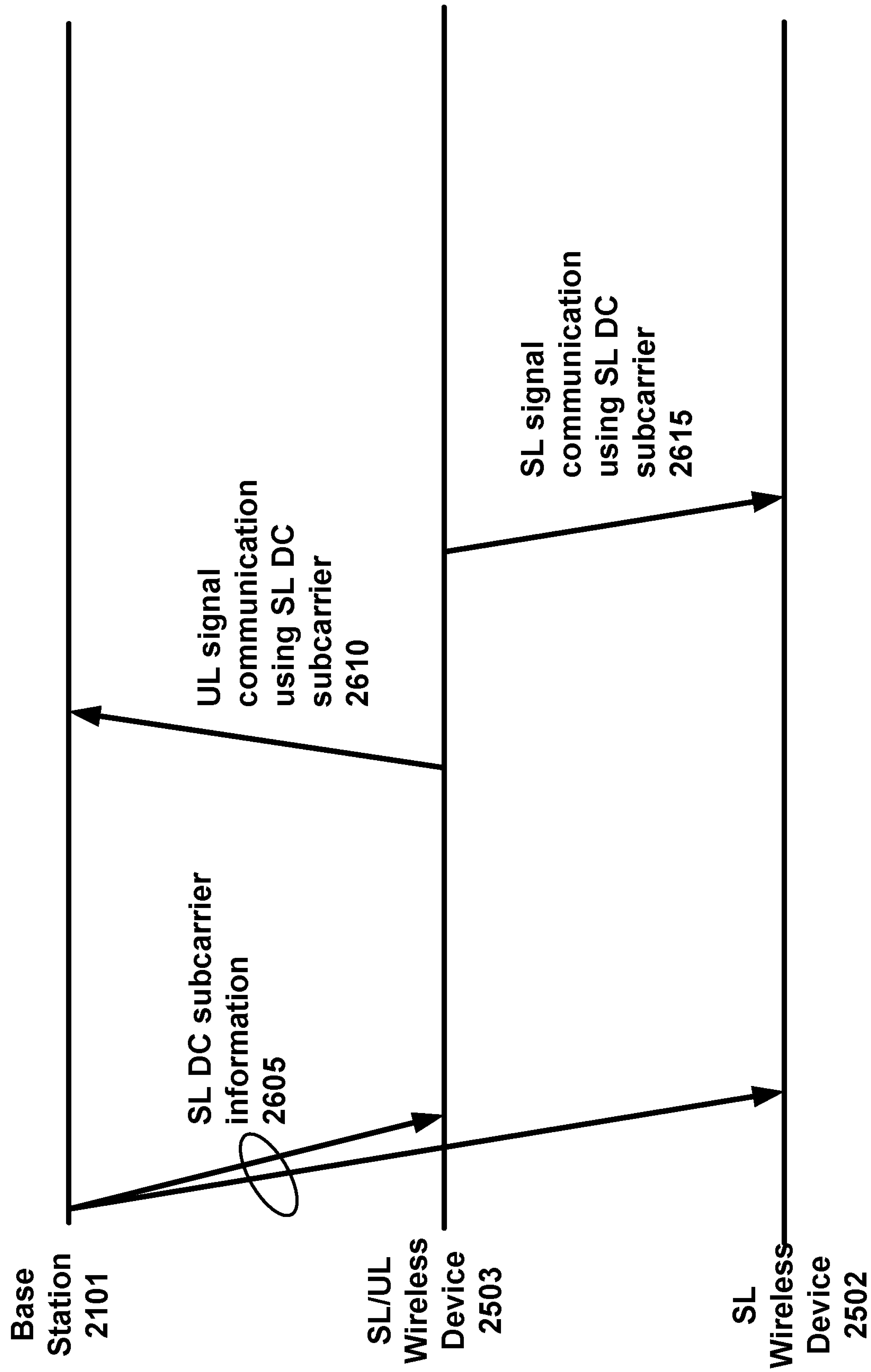

Base Station 2101
SL/UL Wireless Device 2503
SL Wireless Device 2502
SL DC subcarrier information 2605
UL signal communication using SL DC subcarrier 2610
SL signal communication using SL DC subcarrier 2615

FIG. 26

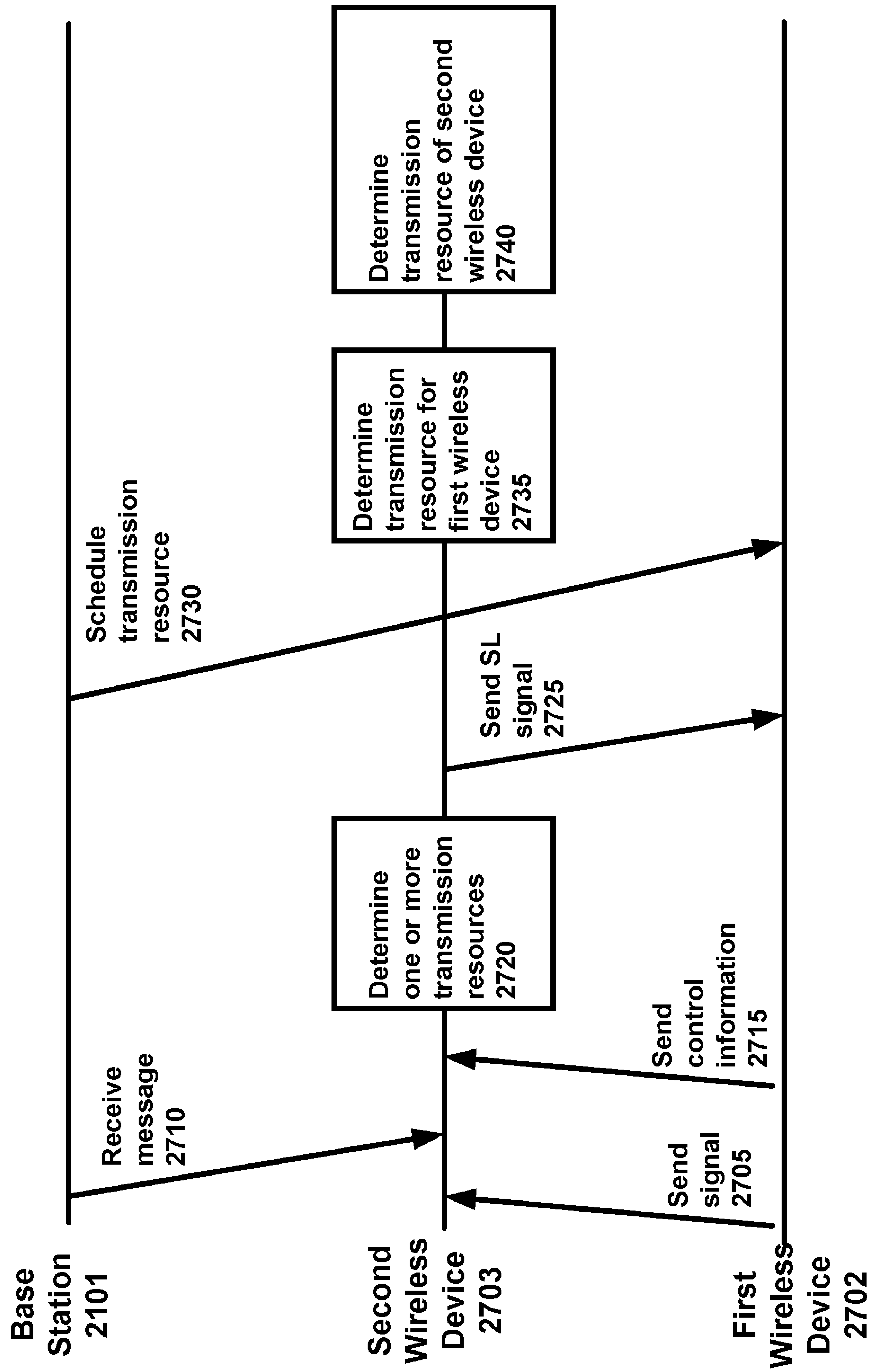

Base Station 2101
Second Wireless Device 2703
First Wireless Device 2702
Send signal 2705
Receive message 2710
Send control information 2715
Determine one or more transmission resources 2720
Send SL signal 2725
Schedule transmission resource 2730
Determine transmission resource for first wireless device 2735
Determine transmission resource of second wireless device 2740

FIG. 27

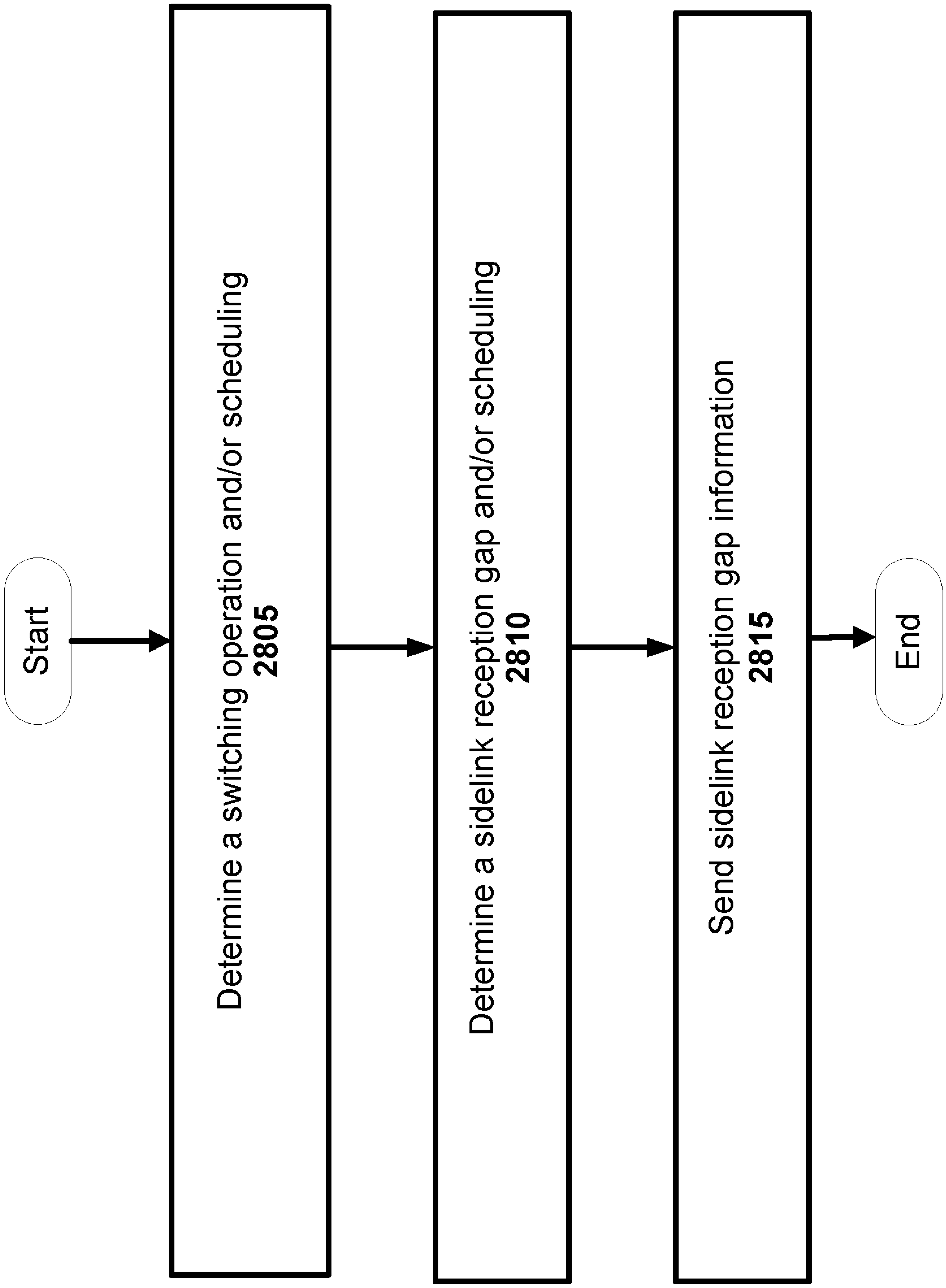

Start
Determine a switching operation and/or scheduling
2805
Determine a sidelink reception gap and/or scheduling
2810
Send sidelink reception gap information
2815
End

FIG. 28

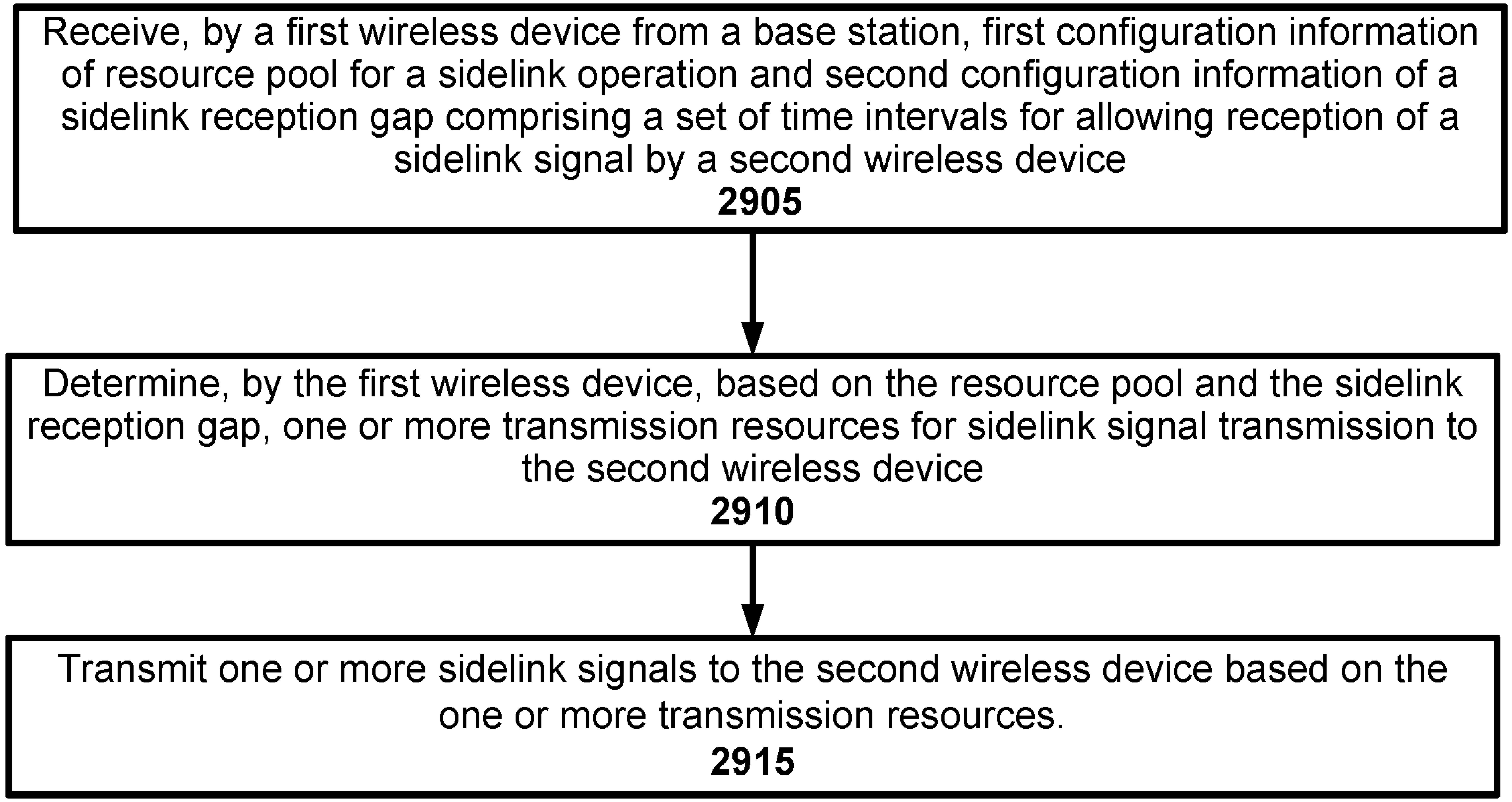
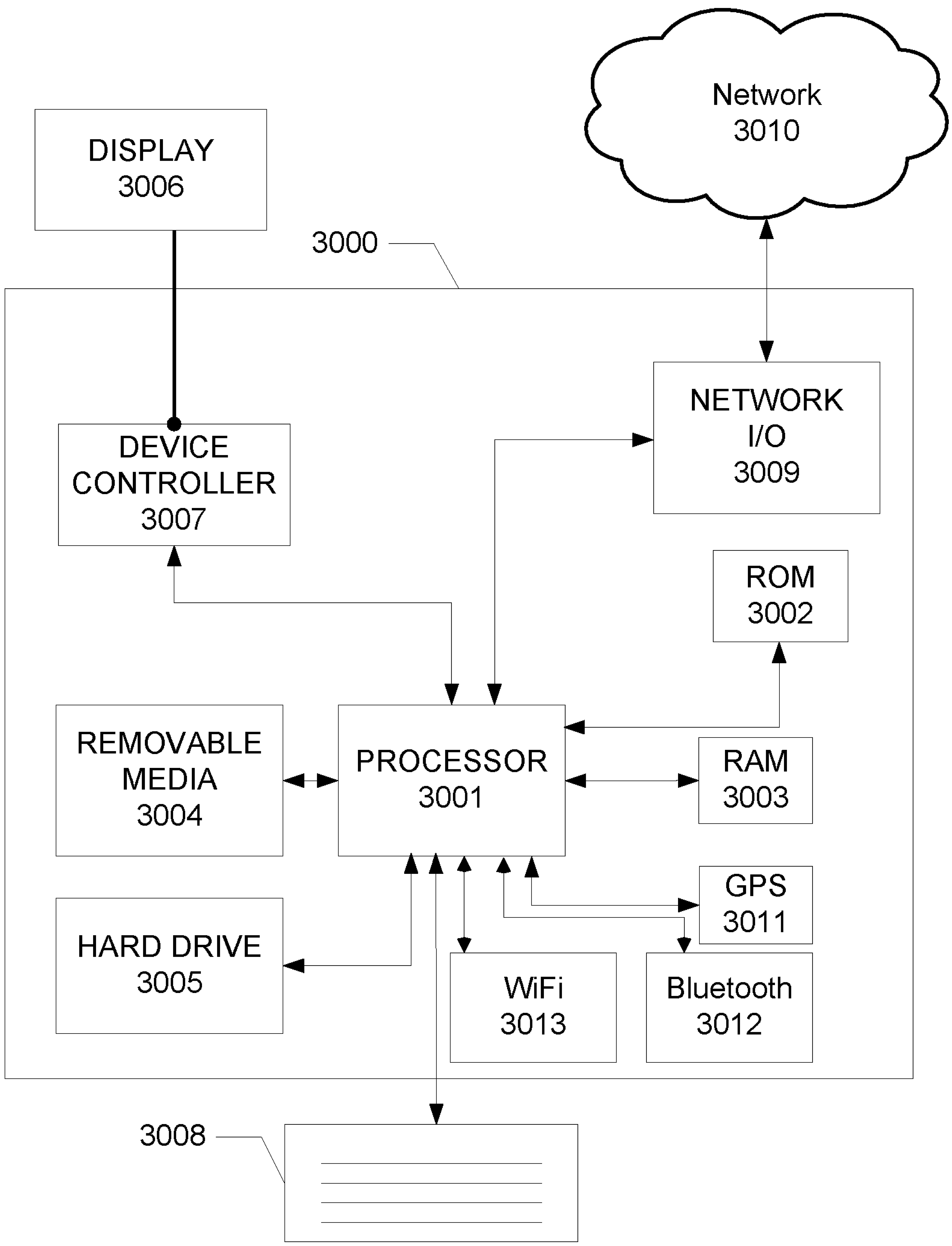

Receive, by a first wireless device from a base station, first configuration information of resource pool for a sidelink operation and second configuration information of a sidelink reception gap comprising a set of time intervals for allowing reception of a sidelink signal by a second wireless device
2905
Determine, by the first wireless device, based on the resource pool and the sidelink reception gap, one or more transmission resources for sidelink signal transmission to the second wireless device
2910
Transmit one or more sidelink signals to the second wireless device based on the one or more transmission resources.
2915

FIG. 29



Network
3010
DISPLAY
3006
3000
NETWORK
I/O
3009
DEVICE
CONTROLLER
3007
ROM
3002
REMOVABLE
MEDIA
3004
PROCESSOR
3001
RAM
3003
GPS
3011
HARD DRIVE
3005
WiFi
3013
Bluetooth
3012
3008

FIG. 30

WIRELESS COMMUNICATIONS FOR A SIDELINK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/842,235 titled "Sidelink Bandwidth Part Interruption Mitigation" and filed on May 2, 2019. The above-referenced application is hereby incorporated by reference in its entirety.

BACKGROUND

Wireless devices may communicate with a base station and/or with other wireless devices. Wireless devices may communicate directly with each other via a sidelink.

SUMMARY

The following summary presents a simplified summary of certain features. The summary is not an extensive overview and is not intended to identify key or critical elements.

Wireless communications are described including, but not limited to, device-to-device communications, vehicle-to-everything communications, vehicle-to-vehicle communications, vehicle-to-network communications, vehicle-to-roadside infrastructure communications, vehicle-to-pedestrian communications, and/or direct communications, such as via a sidelink. A wireless device may not be able to send and/or receive information to/from another wireless device, for example, via a sidelink. A wireless device may not be able to determine whether another wireless device may be able to send and/or receive information to it. If a wireless device sends a message to another wireless device during a time at which the other wireless device is unable to receive it, the sending wireless device may need to resend the message. Resending a message may consume additional power and/or reduce efficiency of wireless communications. To avoid this problem, at least one wireless resource and/or time period may be determined for wireless devices to communicate with each other, for example, via a sidelink. A base station may avoid interrupting sidelink communication, and/or a wireless device may avoid interruptions, based on the determined wireless resource(s) and/or time period(s). Wireless resources (e.g., subcarriers, bandwidth parts, etc.) may be coordinated so that interruptions (e.g., due to bandwidth part switching and/or any or other wireless resource change) may be reduced, which may improve wireless communications.

These and other features and advantages are described in greater detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

Some features are shown by way of example, and not by limitation, in the accompanying drawings. In the drawings, like numerals reference similar elements.

FIG. **1** shows an example radio access network (RAN) architecture.

FIG. **2**A shows an example user plane protocol stack.

FIG. **2**B shows an example control plane protocol stack.

FIG. **3** shows an example wireless device and two base stations.

FIG. **4**A, FIG. **4**B, FIG. **4**C, and FIG. **4**D show examples of uplink and downlink signal transmission.

FIG. **5**A shows an example uplink channel mapping and example uplink physical signals.

FIG. **5**B shows an example downlink channel mapping and example downlink physical signals.

FIG. **6** shows an example transmission time and/or reception time for a carrier.

FIG. **7**A and FIG. **7**B show example sets of orthogonal frequency division multiplexing (OFDM) subcarriers.

FIG. **8** shows example OFDM radio resources.

FIG. **9**A shows an example channel state information reference signal (CSI-RS) and/or synchronization signal (SS) block transmission in a multi-beam system.

FIG. **9**B shows an example downlink beam management procedure.

FIG. **10** shows an example of configured bandwidth parts (BWPs).

FIG. **11**A and FIG. **11**B show examples of multi connectivity.

FIG. **12** shows an example of a random access procedure.

FIG. **13** shows example medium access control (MAC) entities.

FIG. **14** shows an example RAN architecture.

FIG. **15** shows example radio resource control (RRC) states.

FIG. **16**A shows an example of wireless communications between wireless devices without access to a base station of a wireless network.

FIG. **16**B shows an example of wireless communications between wireless devices with one wireless device having access to a base station of a wireless network.

FIG. **16**C shows an example of intra-cell wireless communications between wireless devices having access to a same base station of a wireless network.

FIG. **16**D shows an example of inter-cell wireless communications between wireless devices having accesses to different base stations of a wireless network.

FIG. **17**A shows an example of wireless communications between wireless devices having access to a base station of a wireless network.

FIG. **17**B shows an example of a resource pool for performing wireless communications.

FIG. **18** shows an example of an in-band emissions (IBE) model.

FIG. **19** is shows an example of wireless communications between various vehicles and wireless devices.

FIG. **20**A and FIG. **20**B show example bandwidth part (BWP) configurations.

FIG. **21** shows an example method for coordinating BWP switching.

FIG. **22** shows an example method for coordinating BWP switching.

FIG. **23** shows an example method for coordinating BWP switching.

FIG. **24** shows an example method for coordinating BWP switching.

FIGS. **25**A-C show example methods for coordinating direct current or direct conversion (DC) subcarriers between devices.

FIG. **26** shows an example method for coordinating DC subcarriers between devices.

FIG. **27** shows an example method for coordinating communication resources of devices.

FIG. **28** shows an example method for coordinating communication resources of devices.

FIG. **29** shows an example method for configuring communication resources of devices.

FIG. **30** shows example elements of a computing device that may be used to implement any of the various devices described herein.

DETAILED DESCRIPTION

The accompanying drawings and descriptions provide examples. It is to be understood that the examples shown in the drawings and/or described are non-exclusive and that there are other examples of how features shown and described may be practiced.

The accompanying drawings and descriptions provide examples. It is to be understood that the examples shown in the drawings and/or described are non-exclusive and that there are other examples of how features shown and described may be practiced. Examples are provided for operation of wireless communication systems which may be used in the technical field of multicarrier communication systems. More particularly, the technology described herein may relate sidelink communications for wireless devices.

The following acronyms are used throughout the drawings and/or descriptions, and are provided below for convenience although other acronyms may be introduced in the detailed description:

3GPP 3rd Generation Partnership Project
5G 5th generation mobile networks
5GC 5G Core Network
ACK Acknowledgement
AMF Access and Mobility Management Function
ARQ Automatic Repeat Request
AS Access Stratum
ASIC Application-Specific Integrated Circuit
BA Bandwidth Adaptation
BCCH Broadcast Control Channel
BCH Broadcast Channel
BPSK Binary Phase Shift Keying
BWP Bandwidth Part
CA Carrier Aggregation
CBR Channel Busy Ratio
CC Component Carrier
CCCH Common Control Channel
CDMA Code Division Multiple Access
CE Control Element
CN Core Network
CORESET Control Resource Set
CP Cyclic Prefix
CP-OFDM Cyclic Prefix-Orthogonal Frequency Division Multiplex
C-RNTI Cell-Radio Network Temporary Identifier
CR Channel Occupancy Ratio
CS Configured Scheduling
CSI Channel State Information
CSI-RS Channel State Information-Reference Signal
CQI Channel Quality Indicator
CRI CSI-RS resource indicator
CSS Common Search Space
CU Central Unit
D2D device to device
DC Dual Connectivity
DCCH Dedicated Control Channel
DCI Downlink Control Information
DL Downlink
DL-SCH Downlink Shared Channel
DM-RS DeModulation Reference Signal
DRB Data Radio Bearer
DRX Discontinuous Reception
DTCH Dedicated Traffic Channel
DU Distributed Unit
eNB
EPC Evolved Packet Core
E-UTRA Evolved UMTS Terrestrial Radio Access
E-UTRAN Evolved-Universal Terrestrial Radio Access Network
FDD Frequency Division Duplex
FPGA Field Programmable Gate Arrays
F1-C F1-Control plane
F1-U F1-User plane
GNSS Global Navigation Satellite System
GPS Global Positioning System
gNB next generation Node B
HARQ Hybrid Automatic Repeat bequest
HDL Hardware Description Languages
IE Information Element
IBE In-Band Emission
IP Internet Protocol
LCID Logical Channel Identifier
LI Layer Indicator
LTE Long Term Evolution
MAC Medium Access Control
MCG Master Cell Group
MCS Modulation and Coding Scheme
MeNB Master evolved Node B
MIB Master Information Block
MIMO
MME Mobility Management Entity
MN Master Node
MU-MIMO multi-user-MIMO
NACK Negative Acknowledgement
NAS Non-Access Stratum
NDI New Data Indicator
NG CP Next Generation Control Plane
NGC Next Generation Core
NG-C NG-Control plane
ng-eNB next generation evolved Node B
NG-U NG-User plane
NR New Radio
NR MAC New Radio MAC
NR PDCP New Radio PDCP
NR PHY New Radio PHYsical
NR RLC New Radio RLC
NR RRC New Radio RRC
NR UE New Radio UE
NSSAI Network Slice Selection Assistance Information
O&M Operation and Maintenance
OFDM Orthogonal Frequency Division Multiplexing
PBCH Physical Broadcast Channel
PCC Primary Component Carrier
PCCH Paging Control Channel
Pcell Primary Cell
PCH Paging Channel
PDCCH Physical Downlink Control Channel
PDCP Packet Data Convergence Protocol
PDSCH Physical Downlink Shared Channel
PDU Protocol Data Unit
PHICH Physical HARQ Indicator Channel
PHY PHYsical
PLMN Public Land Mobile Network
PMI Precoding Matrix Indicator
PRACH Physical Random Access Channel
PRB Physical Resource Block
PSBCH Physical Sidelink Broadcast Channel
PSCCH Physical Sidelink Control Channel
PSCell Primary Secondary Cell
PSDCH Physical Sidelink Discovery Channel
PSS Primary Synchronization Signal
PSSCH Physical Sidelink Shared Channel
pTAG primary Timing Advance Group
PT-RS Phase Tracking Reference Signal

PUCCH Physical Uplink Control Channel
PUSCH Physical Uplink Shared Channel
QAM Quadrature Amplitude Modulation
QCLed Quasi-Co-Located
QCL Quasi-Co-Location
QFI Quality of Service Indicator
QoS Quality of Service
QPSK Quadrature Phase Shift Keying
RA Random Access
RACH Random Access Channel
RAN Radio Access Network
RAT Radio Access Technology
RA-RNTI Random Access-Radio Network Temporary Identifier
RB Resource Blocks
RBG Resource Block Groups
RE Resource Element
RI Rank indicator
RLC Radio Link Control
RLM Radio Link Monitoring
RNTI Radio Network Temporary Identifier
RRC Radio Resource Control
RRM Radio Resource Management
RS Reference Signal
RSSI Received Signal Strength Indicator
RSU Roadside Unit
RV Redundancy Version
RSRP Reference Signal Received Power
S-PSS Sidelink Primary Synchronization Signal
S-SSB Sidelink Synchronization Signal Block
S-SSS Sidelink Secondary Synchronization Signal
SCC Secondary Component Carrier
Scell Secondary Cell
SCG Secondary Cell Group
SCS
SC-FDMA Single Carrier-Frequency Division Multiple Access
SDAP Service Data Adaptation Protocol
SDU Service Data Unit
SeNB Secondary evolved Node B
SFN System Frame Number
S-GW Serving GateWay
SI System Information
SIB System Information Block
SINR Signal-to-Interference-plus-Noise Ratio
SLSS Sidelink Synchronization Signal
SMF Session Management Function
SN Secondary Node
SpCell Special Cell
SRB Signaling Radio Bearer
SRS Sounding Reference Signal
SS Synchronization Signal
SSB Synchronization Signal Block
SSBRI Synchronization Signal Block Resource Indicator
SSS Secondary Synchronization Signal
sTAG secondary Timing Advance Group
TA Timing Advance
TAG Timing Advance Group
TAI Tracking Area Identifier
TAT Time Alignment Timer
TB Transport Block
TC-RNTI Temporary Cell-Radio Network Temporary Identifier
TCI Transmission Configuration Indication
TDD Time Division Duplex
TDMA Time Division Multiple Access
TRP Transmission Reception Point
TTI Transmission Time Interval
UCI Uplink Control Information
UE User Equipment
UL Uplink
UL-SCH Uplink Shared Channel
UPF User Plane Function
UPGW User Plane Gateway
URLLC Ultra-Reliable Low-Latency Communication
V2X Vehicle-to-everything
V2P Vehicle-to-pedestrian
V2V Vehicle-to-vehicle
V2I Vehicle-to-infrastructure
V2N Vehicle-to-network
V2I/N Vehicle-to-infrastructure/network
VHDL VHSIC Hardware Description Language
VHSIC Very High Speed Integrated Circuit
Xn-C Xn-Control plane
Xn-U Xn-User plane

Examples described herein may be implemented using various physical layer modulation and transmission mechanisms. Example transmission mechanisms may include, but are not limited to: Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Time Division Multiple Access (TDMA), Wavelet technologies, and/or the like. Hybrid transmission mechanisms such as TDMA/CDMA, and/or OFDM/CDMA may be used. Various modulation schemes may be used for signal transmission in the physical layer. Examples of modulation schemes include, but are not limited to: phase, amplitude, code, a combination of these, and/or the like. An example radio transmission method may implement Quadrature Amplitude Modulation (QAM) using Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16-QAM, 64-QAM, 256-QAM, 1024-QAM and/or the like. Physical radio transmission may be enhanced by dynamically or semi-dynamically changing the modulation and coding scheme, for example, depending on transmission requirements and/or radio conditions.

FIG. **1** shows an example Radio Access Network (RAN) architecture. A RAN node may comprise a next generation Node B (gNB) (e.g., **120**A, **120**B) providing New Radio (NR) user plane and control plane protocol terminations towards a first wireless device (e.g., **110**A). A RAN node may comprise a base station such as a next generation evolved Node B (ng-eNB) (e.g., **120**C, **120**D), providing Evolved UMTS Terrestrial Radio Access (E-UTRA) user plane and control plane protocol terminations towards a second wireless device (e.g., **110**B). A first wireless device **110**A may communicate with a base station, such as a gNB **120**A, over a Uu interface. A second wireless device **110**B may communicate with a base station, such as an ng-eNB **120**D, over a Uu interface. The wireless devices **110**A and/or **110**B may be structurally similar to wireless devices shown in and/or described in connection with other drawing figures. The Node B **120**A, the Node B **120**B, the Node B **120**C, and/or the Node B **120**D may be structurally similar to Nodes B and/or base stations shown in and/or described in connection with other drawing figures.

A base station, such as a gNB (e.g., **120**A, **120**B, etc.) and/or an ng-eNB (e.g., **120**C, **120**D, etc.) may host functions such as radio resource management and scheduling, IP header compression, encryption and integrity protection of data, selection of Access and Mobility Management Function (AMF) at wireless device (e.g., User Equipment (UE)) attachment, routing of user plane and control plane data, connection setup and release, scheduling and transmission of paging messages (e.g., originated from the AMF), scheduling and transmission of system broadcast information (e.g., originated from the AMF or Operation and Maintenance (O&M)), measurement and measurement reporting configuration, transport level packet marking in the uplink, session management, support of network slicing, Quality of Service (QoS) flow management and mapping to data radio bearers, support of wireless devices in an inactive state (e.g., RRC_INACTIVE state), distribution function for Non-Access Stratum (NAS) messages, RAN sharing, dual connectivity, and/or tight interworking between NR and E-UTRA.

One or more first base stations (e.g., gNBs **120**A and **120**B) and/or one or more second base stations (e.g., ng-eNBs **120**C and **120**D) may be interconnected with each other via Xn interface. A first base station (e.g., gNB **120**A, **120**B, etc.) or a second base station (e.g., ng-eNB **120**C, **120**D, etc.) may be connected via NG interfaces to a network, such as a 5G Core Network (5GC). A 5GC may comprise one or more AMF/User Plan Function (UPF) functions (e.g., **130**A and/or **130**B). A base station (e.g., a gNB and/or an ng-eNB) may be connected to a UPF via an NG-User plane (NG-U) interface. The NG-U interface may provide delivery (e.g., non-guaranteed delivery) of user plane Protocol Data Units (PDUs) between a RAN node and the UPF. A base station (e.g., a gNB and/or an ng-eNB) may be connected to an AMF via an NG-Control plane (NG-C) interface. The NG-C interface may provide functions such as NG interface management, wireless device (e.g., UE) context management, wireless device (e.g., UE) mobility management, transport of NAS messages, paging, PDU session management, configuration transfer, and/or warning message transmission.

A UPF may host functions such as anchor point for intra-/inter-Radio Access Technology (RAT) mobility (e.g., if applicable), external PDU session point of interconnect to data network, packet routing and forwarding, packet inspection and user plane part of policy rule enforcement, traffic usage reporting, uplink classifier to support routing traffic flows to a data network, branching point to support multi-homed PDU session, quality of service (QoS) handling for user plane, packet filtering, gating, Uplink (UL)/Downlink (DL) rate enforcement, uplink traffic verification (e.g., Service Data Flow (SDF) to QoS flow mapping), downlink packet buffering, and/or downlink data notification triggering.

An AMF may host functions such as NAS signaling termination, NAS signaling security, Access Stratum (AS) security control, inter Core Network (CN) node signaling (e.g., for mobility between 3rd Generation Partnership Project (3GPP) access networks), idle mode wireless device reachability (e.g., control and execution of paging retransmission), registration area management, support of intra-system and inter-system mobility, access authentication, access authorization including check of roaming rights, mobility management control (e.g., subscription and/or policies), support of network slicing, and/or Session Management Function (SMF) selection.

FIG. **2**A shows an example user plane protocol stack. A Service Data Adaptation Protocol (SDAP) (e.g., **211** and **221**), Packet Data Convergence Protocol (PDCP) (e.g., **212** and **222**), Radio Link Control (RLC) (e.g., **213** and **223**), and Medium Access Control (MAC) (e.g., **214** and **224**) sublayers, and a Physical (PHY) (e.g., **215** and **225**) layer, may be terminated in a wireless device (e.g., **110**) and in a base station (e.g., **120**) on a network side. A PHY layer may provide transport services to higher layers (e.g., MAC, RRC, etc.). Services and/or functions of a MAC sublayer may comprise mapping between logical channels and transport channels, multiplexing and/or demultiplexing of MAC Service Data Units (SDUs) belonging to the same or different logical channels into and/or from Transport Blocks (TBs) delivered to and/or from the PHY layer, scheduling information reporting, error correction through Hybrid Automatic Repeat request (HARQ) (e.g., one HARQ entity per carrier for Carrier Aggregation (CA)), priority handling between wireless devices such as by using dynamic scheduling, priority handling between logical channels of a wireless device such as by using logical channel prioritization, and/or padding. A MAC entity may support one or multiple numerologies and/or transmission timings. Mapping restrictions in a logical channel prioritization may control which numerology and/or transmission timing a logical channel may use. An RLC sublayer may support transparent mode (TM), unacknowledged mode (UM), and/or acknowledged mode (AM) transmission modes. The RLC configuration may be per logical channel with no dependency on numerologies and/or Transmission Time Interval (TTI) durations. Automatic Repeat Request (ARQ) may operate on any of the numerologies and/or TTI durations with which the logical channel is configured. Services and functions of the PDCP layer for the user plane may comprise, for example, sequence numbering, header compression and decompression, transfer of user data, reordering and duplicate detection, PDCP PDU routing (e.g., such as for split bearers), retransmission of PDCP SDUs, ciphering, deciphering and integrity protection, PDCP SDU discard, PDCP re-establishment and data recovery for RLC AM, and/or duplication of PDCP PDUs. Services and/or functions of SDAP may comprise, for example, mapping between a QoS flow and a data radio bearer. Services and/or functions of SDAP may comprise mapping a Quality of Service Indicator (QFI) in DL and UL packets. A protocol entity of SDAP may be configured for an individual PDU session.

FIG. **2**B shows an example control plane protocol stack. A PDCP (e.g., **233** and **242**), RLC (e.g., **234** and **243**), and MAC (e.g., **235** and **244**) sublayers, and a PHY (e.g., **236** and **245**) layer, may be terminated in a wireless device (e.g., **110**), and in a base station (e.g., **120**) on a network side, and perform service and/or functions described above. RRC (e.g., **232** and **241**) may be terminated in a wireless device and a base station on a network side. Services and/or functions of RRC may comprise broadcast of system information related to AS and/or NAS; paging (e.g., initiated by a 5GC or a RAN); establishment, maintenance, and/or release of an RRC connection between the wireless device and RAN; security functions such as key management, establishment, configuration, maintenance, and/or release of Signaling Radio Bearers (SRBs) and Data Radio Bearers (DRBs); mobility functions; QoS management functions; wireless device measurement reporting and control of the reporting; detection of and recovery from radio link failure; and/or NAS message transfer to/from NAS from/to a wireless device. NAS control protocol (e.g., **231** and **251**) may be terminated in the wireless device and AMF (e.g., **130**) on a network side. NAS control protocol may perform functions such as authentication, mobility management between a wireless device and an AMF (e.g., for 3GPP access and non-3GPP access), and/or session management between a wireless device and an SMF (e.g., for 3GPP access and non-3GPP access).

A base station may configure a plurality of logical channels for a wireless device. A logical channel of the plurality of logical channels may correspond to a radio bearer. The radio bearer may be associated with a QoS requirement. A base station may configure a logical channel to be mapped to one or more TTIs and/or numerologies in a plurality of TTIs and/or numerologies. The wireless device may receive Downlink Control Information (DCI) via a Physical Downlink Control CHannel (PDCCH) indicating an uplink grant. The uplink grant may be for a first TTI and/or a first numerology and may indicate uplink resources for transmission of a transport block. The base station may configure each logical channel in the plurality of logical channels with one or more parameters to be used by a logical channel prioritization procedure at the MAC layer of the wireless device. The one or more parameters may comprise, for example, priority, prioritized bit rate, etc. A logical channel in the plurality of logical channels may correspond to one or more buffers comprising data associated with the logical channel. The logical channel prioritization procedure may allocate the uplink resources to one or more first logical channels in the plurality of logical channels and/or to one or more MAC Control Elements (Ces). The one or more first logical channels may be mapped to the first TTI and/or the first numerology. The MAC layer at the wireless device may multiplex one or more MaC Ces and/or one or more MAC SDUs (e.g., logical channel) in a MAC PDU (e.g., transport block). The MAC PDU may comprise a MAC header comprising a plurality of MAC sub-headers. A MAC sub-header in the plurality of MAC sub-headers may correspond to a MAC CE or a MAC SUD (e.g., logical channel) in the one or more MaC Ces and/or in the one or more MAC SDUs. A MAC CE and/or a logical channel may be configured with a Logical Channel Identifier (LCID). An LCID for a logical channel and/or a MAC CE may be fixed and/or pre-configured. An LCID for a logical channel and/or MAC CE may be configured for the wireless device by the base station. The MAC sub-header corresponding to a MAC CE and/or a MAC SDU may comprise an LCID associated with the MAC CE and/or the MAC SDU.

A base station may activate, deactivate, and/or impact one or more processes (e.g., set values of one or more parameters of the one or more processes or start and/or stop one or more timers of the one or more processes) at the wireless device, for example, by using one or more MAC commands. The one or more MAC commands may comprise one or more MAC control elements. The one or more processes may comprise activation and/or deactivation of PDCP packet duplication for one or more radio bearers. The base station may send (e.g., transmit) a MAC CE comprising one or more fields. The values of the fields may indicate activation and/or deactivation of PDCP duplication for the one or more radio bearers. The one or more processes may comprise Channel State Information (CSI) transmission of on one or more cells. The base station may send (e.g., transmit) one or more MaC Ces indicating activation and/or deactivation of the CSI transmission on the one or more cells. The one or more processes may comprise activation and/or deactivation of one or more secondary cells. The base station may send (e.g., transmit) a MAC CE indicating activation and/or deactivation of one or more secondary cells. The base station may send (e.g., transmit) one or more MaC Ces indicating starting and/or stopping of one or more Discontinuous Reception (DRX) timers at the wireless device. The base station may send (e.g., transmit) one or more MaC Ces indicating one or more timing advance values for one or more Timing Advance Groups (TAGs).

FIG. **3** shows an example of base stations (base station **1**, **120**A, and base station **2**, **120**B) and a wireless device **110**. The wireless device **110** may comprise a UE or any other wireless device. The base station (e.g., **120**A, **120**B) may comprise a Node B, eNB, gNB, ng-eNB, one or more transmission and reception points, or any other base station. A wireless device and/or a base station may perform one or more functions of a relay node. The base station **1**, **120**A, may comprise at least one communication interface **320**A (e.g., a wireless modem, an antenna, a wired modem, and/or the like), at least one processor **321**A, and at least one set of program code instructions **323**A that may be stored in non-transitory memory **322**A and executable by the at least one processor **321**A. The base station **2**, **120**B, may comprise at least one communication interface **320**B, at least one processor **321**B, and at least one set of program code instructions **323**B that may be stored in non-transitory memory **322**B and executable by the at least one processor **321**B.

A base station may comprise any number of sectors, for example: 1, 2, 3, 4, or 6 sectors. A base station may comprise any number of cells, for example, ranging from 1 to 50 cells or more. A cell may be categorized, for example, as a primary cell or secondary cell. At Radio Resource Control (RRC) connection establishment, re-establishment, handover, etc., a serving cell may provide NAS (non-access stratum) mobility information (e.g., Tracking Area Identifier (TAI)). At RRC connection re-establishment and/or handover, a serving cell may provide security input. This serving cell may be referred to as the Primary Cell (Pcell). In the downlink, a carrier corresponding to the Pcell may be a DL Primary Component Carrier (PCC). In the uplink, a carrier may be an UL PCC. Secondary Cells (Scells) may be configured to form together with a Pcell a set of serving cells, for example, depending on wireless device capabilities. In a downlink, a carrier corresponding to an Scell may be a downlink secondary component carrier (DL SCC). In an uplink, a carrier may be an uplink secondary component carrier (UL SCC). An Scell may or may not have an uplink carrier.

A cell, comprising a downlink carrier and optionally an uplink carrier, may be assigned a physical cell ID and/or a cell index. A carrier (downlink and/or uplink) may belong to one cell. The cell ID and/or cell index may identify the downlink carrier and/or uplink carrier of the cell (e.g., depending on the context it is used). A cell ID may be equally referred to as a carrier ID, and a cell index may be referred to as a carrier index. A physical cell ID and/or a cell index may be assigned to a cell. A cell ID may be determined using a synchronization signal transmitted via a downlink carrier. A cell index may be determined using RRC messages. A first physical cell ID for a first downlink carrier may indicate that the first physical cell ID is for a cell comprising the first downlink carrier. The same concept may be used, for example, with carrier activation and/or deactivation (e.g., secondary cell activation and/or deactivation). A first carrier that is activated may indicate that a cell comprising the first carrier is activated.

A base station may send (e.g., transmit) to a wireless device one or more messages (e.g., RRC messages) comprising a plurality of configuration parameters for one or more cells. One or more cells may comprise at least one primary cell and at least one secondary cell. An RRC message may be broadcasted and/or unicasted to the wireless device. Configuration parameters may comprise common parameters and dedicated parameters.

Services and/or functions of an RRC sublayer may comprise at least one of: broadcast of system information related to AS and/or NAS; paging initiated by a 5GC and/or an NG-RAN; establishment, maintenance, and/or release of an RRC connection between a wireless device and an NG-RAN, which may comprise at least one of addition, modification, and/or release of carrier aggregation; and/or addition, modification, and/or release of dual connectivity in NR or between E-UTRA and NR. Services and/or functions of an RRC sublayer may comprise at least one of security functions comprising key management; establishment, configuration, maintenance, and/or release of Signaling Radio Bearers (SRBs) and/or Data Radio Bearers (DRBs); mobility functions which may comprise at least one of a handover (e.g., intra NR mobility or inter-RAT mobility) and/or a context transfer; and/or a wireless device cell selection and/or reselection and/or control of cell selection and reselection. Services and/or functions of an RRC sublayer may comprise at least one of QoS management functions; a wireless device measurement configuration/reporting; detection of and/or recovery from radio link failure; and/or NAS message transfer to and/or from a core network entity (e.g., AMF, Mobility Management Entity (MME)) from and/or to the wireless device.

An RRC sublayer may support an RRC_Idle state, an RRC_Inactive state, and/or an RRC_Connected state for a wireless device. In an RRC_Idle state, a wireless device may perform at least one of: Public Land Mobile Network (PLMN) selection; receiving broadcasted system information; cell selection and/or re-selection; monitoring and/or receiving a paging for mobile terminated data initiated by 5GC; paging for mobile terminated data area managed by 5GC; and/or DRX for CN paging configured via NAS. In an RRC_Inactive state, a wireless device may perform at least one of: receiving broadcasted system information; cell selection and/or re-selection; monitoring and/or receiving a RAN and/or CN paging initiated by an NG-RAN and/or a 5GC; RAN-based notification area (RNA) managed by an NG-RAN; and/or DRX for a RAN and/or CN paging configured by NG-RAN/NAS. In an RRC_Idle state of a wireless device, a base station (e.g., NG-RAN) may keep a 5GC-NG-RAN connection (e.g., both C/U-planes) for the wireless device; and/or store a wireless device AS context for the wireless device. In an RRC_Connected state of a wireless device, a base station (e.g., NG-RAN) may perform at least one of: establishment of 5GC-NG-RAN connection (both C/U-planes) for the wireless device; storing a UE AS context for the wireless device; send (e.g., transmit) and/or receive of unicast data to and/or from the wireless device; and/or network-controlled mobility based on measurement results received from the wireless device. In an RRC_Connected state of a wireless device, an NG-RAN may know a cell to which the wireless device belongs.

System information (SI) may be divided into minimum SI and other SI. The minimum SI may be periodically broadcast. The minimum SI may comprise basic information required for initial access and/or information for acquiring any other SI broadcast periodically and/or provisioned on-demand (e.g., scheduling information). The other SI may either be broadcast, and/or be provisioned in a dedicated manner, such as either triggered by a network and/or upon request from a wireless device. A minimum SI may be transmitted via two different downlink channels using different messages (e.g., MasterInformationBlock and SystemInformationBlockType1). Another SI may be transmitted via SystemInformationBlockType2. For a wireless device in an RRC_Connected state, dedicated signaling may be used for the request and delivery of the other SI. For the wireless device in the RRC_Idle state and/or in the RRC_Inactive state, the request may trigger a random access procedure.

A wireless device may report its radio access capability information, which may be static. A base station may request one or more indications of capabilities for a wireless device to report based on band information. A temporary capability restriction request may be sent by the wireless device (e.g., if allowed by a network) to signal the limited availability of some capabilities (e.g., due to hardware sharing, interference, and/or overheating) to the base station. The base station may confirm or reject the request. The temporary capability restriction may be transparent to 5GC (e.g., static capabilities may be stored in 5GC).

A wireless device may have an RRC connection with a network, for example, if CA is configured. At RRC connection establishment, re-establishment, and/or handover procedures, a serving cell may provide NAS mobility information. At RRC connection re-establishment and/or handover, a serving cell may provide a security input. This serving cell may be referred to as the Pcell. Scells may be configured to form together with the Pcell a set of serving cells, for example, depending on the capabilities of the wireless device. The configured set of serving cells for the wireless device may comprise a Pcell and one or more Scells.

The reconfiguration, addition, and/or removal of Scells may be performed by RRC messaging. At intra-NR handover, RRC may add, remove, and/or reconfigure Scells for usage with the target Pcell. Dedicated RRC signaling may be used (e.g., if adding a new Scell) to send all required system information of the Scell (e.g., if in connected mode, wireless devices may not acquire broadcasted system information directly from the Scells).

The purpose of an RRC connection reconfiguration procedure may be to modify an RRC connection, (e.g., to establish, modify, and/or release RBs; to perform handover; to setup, modify, and/or release measurements, for example, to add, modify, and/or release Scells and cell groups). NAS dedicated information may be transferred from the network to the wireless device, for example, as part of the RRC connection reconfiguration procedure. The RRCConnectionReconfiguration message may be a command to modify an RRC connection. One or more RRC messages may convey information for measurement configuration, mobility control, and/or radio resource configuration (e.g., RBs, MAC main configuration, and/or physical channel configuration), which may comprise any associated dedicated NAS information and/or security configuration. The wireless device may perform an Scell release, for example, if the received RRC Connection Reconfiguration message includes the sCellToReleaseList. The wireless device may perform Scell additions or modification, for example, if the received RRC Connection Reconfiguration message includes the sCellToAddModList.

An RRC connection establishment, reestablishment, and/or resume procedure may be to establish, reestablish, and/or resume an RRC connection, respectively. An RRC connection establishment procedure may comprise SRB1 establishment. The RRC connection establishment procedure may be used to transfer the initial NAS dedicated information and/or message from a wireless device to an E-UTRAN. The RRCConnectionReestablishment message may be used to re-establish SRB1.

A measurement report procedure may be used to transfer measurement results from a wireless device to an NG-RAN. The wireless device may initiate a measurement report procedure, for example, after successful security activation. A measurement report message may be used to send (e.g., transmit) measurement results.

The wireless device **110** may comprise at least one communication interface **310** (e.g., a wireless modem, an antenna, and/or the like), at least one processor **314**, and at least one set of program code instructions **316** that may be stored in non-transitory memory **315** and executable by the at least one processor **314**. The wireless device **110** may further comprise at least one of at least one speaker and/or microphone **311**, at least one keypad **312**, at least one display and/or touchpad **313**, at least one power source **317**, at least one global positioning system (GPS) chipset **318**, and/or other peripherals **319**.

The processor **314** of the wireless device **110**, the processor **321**A of the base station **1 120**A, and/or the processor **321**B of the base station **2 120**B may comprise at least one of a general-purpose processor, a digital signal processor (DSP), a controller, a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) and/or other programmable logic device, discrete gate and/or transistor logic, discrete hardware components, and/or the like. The processor **314** of the wireless device **110**, the processor **321**A in base station **1 120**A, and/or the processor **321**B in base station **2 120**B may perform at least one of signal coding and/or processing, data processing, power control, input/output processing, and/or any other functionality that may enable the wireless device **110**, the base station **1 120**A and/or the base station **2 120**B to operate in a wireless environment.

The processor **314** of the wireless device **110** may be connected to and/or in communication with the speaker and/or microphone **311**, the keypad **312**, and/or the display and/or touchpad **313**. The processor **314** may receive user input data from and/or provide user output data to the speaker and/or microphone **311**, the keypad **312**, and/or the display and/or touchpad **313**. The processor **314** in the wireless device **110** may receive power from the power source **317** and/or may be configured to distribute the power to the other components in the wireless device **110**. The power source **317** may comprise at least one of one or more dry cell batteries, solar cells, fuel cells, and/or the like. The processor **314** may be connected to the GPS chipset **318**. The GPS chipset **318** may be configured to provide geographic location information of the wireless device **110**.

The processor **314** of the wireless device **110** may further be connected to and/or in communication with other peripherals **319**, which may comprise one or more software and/or hardware modules that may provide additional features and/or functionalities. For example, the peripherals **319** may comprise at least one of an accelerometer, a satellite transceiver, a digital camera, a universal serial bus (USB) port, a hands-free headset, a frequency modulated (FM) radio unit, a media player, an Internet browser, and/or the like.

The communication interface **320**A of the base station **1**, **120**A, and/or the communication interface **320**B of the base station **2**, **120**B, may be configured to communicate with the communication interface **310** of the wireless device **110**, for example, via a wireless link **330**A and/or via a wireless link **330**B, respectively. The communication interface **320**A of the base station **1**, **120**A, may communicate with the communication interface **320**B of the base station **2** and/or other RAN and/or core network nodes.

The wireless link **330**A and/or the wireless link **330**B may comprise at least one of a bi-directional link and/or a directional link. The communication interface **310** of the wireless device **110** may be configured to communicate with the communication interface **320**A of the base station **1 120**A and/or with the communication interface **320**B of the base station **2 120**B. The base station **1 120**A and the wireless device **110**, and/or the base station **2 120**B and the wireless device **110**, may be configured to send and receive transport blocks, for example, via the wireless link **330**A and/or via the wireless link **330**B, respectively. The wireless link **330**A and/or the wireless link **330**B may use at least one frequency carrier. Transceiver(s) may be used. A transceiver may be a device that comprises both a transmitter and a receiver. Transceivers may be used in devices such as wireless devices, base stations, relay nodes, computing devices, and/or the like. Radio technology may be implemented in the communication interface **310**, **320**A, and/or **320**B, and the wireless link **330**A and/or **330**B. The radio technology may comprise one or more elements shown in FIG. **4**A, FIG. **4**B, FIG. **4**C, FIG. **4**D, FIG. **6**, FIG. **7**A, FIG. **7**B, FIG. **8**, and associated text, described below.

Other nodes in a wireless network (e.g. AMF, UPF, SMF, etc.) may comprise one or more communication interfaces, one or more processors, and memory storing instructions. A node (e.g., wireless device, base station, AMF, SMF, UPF, servers, switches, antennas, and/or the like) may comprise one or more processors, and memory storing instructions that when executed by the one or more processors causes the node to perform certain processes and/or functions. Single-carrier and/or multi-carrier communication operation may be performed. A non-transitory tangible computer readable media may comprise instructions executable by one or more processors to cause operation of single-carrier and/or multi-carrier communications. An article of manufacture may comprise a non-transitory tangible computer readable machine-accessible medium having instructions encoded thereon for enabling programmable hardware to cause a node to enable operation of single-carrier and/or multi-carrier communications. The node may include processors, memory, interfaces, and/or the like.

An interface may comprise at least one of a hardware interface, a firmware interface, a software interface, and/or a combination thereof. The hardware interface may comprise connectors, wires, and/or electronic devices such as drivers, amplifiers, and/or the like. The software interface may comprise code stored in a memory device to implement protocol(s), protocol layers, communication drivers, device drivers, combinations thereof, and/or the like. The firmware interface may comprise a combination of embedded hardware and/or code stored in (and/or in communication with) a memory device to implement connections, electronic device operations, protocol(s), protocol layers, communication drivers, device drivers, hardware operations, combinations thereof, and/or the like.

A communication network may comprise the wireless device **110**, the base station **1**, **120**A, the base station **2**, **120**B, and/or any other device. The communication network may comprise any number and/or type of devices, such as, for example, computing devices, wireless devices, mobile devices, handsets, tablets, laptops, internet of things (IoT) devices, hotspots, cellular repeaters, computing devices, and/or, more generally, user equipment (e.g., UE). Although one or more of the above types of devices may be referenced herein (e.g., UE, wireless device, computing device, etc.), it should be understood that any device herein may comprise any one or more of the above types of devices or similar devices. The communication network, and any other network referenced herein, may comprise an LTE network, a 5G network, or any other network for wireless communications. Apparatuses, systems, and/or methods described herein may generally be described as implemented on one or more devices (e.g., wireless device, base station, eNB, gNB, computing device, etc.), in one or more networks, but it will be understood that one or more features and steps may be implemented on any device and/or in any network. As used throughout, the term “base station” may comprise one or more of: a base station, a node, a Node B, a gNB, an eNB, an ng-eNB, a relay node (e.g., an integrated access and backhaul (IAB) node), a donor node (e.g., a donor eNB, a donor gNB, etc.), an access point (e.g., a WiFi access point), a computing device, a device capable of wirelessly communicating, or any other device capable of sending and/or receiving signals. As used throughout, the term "wireless device" may comprise one or more of: a UE, a handset, a mobile device, a computing device, a node, a device capable of wirelessly communicating, or any other device capable of sending and/or receiving signals. Any reference to one or more of these terms/devices also considers use of any other term/device mentioned above.

FIG. **4**A, FIG. **4**B, FIG. **4**C and FIG. **4**D show examples of uplink and downlink signal transmission. FIG. **4**A shows an example uplink transmitter for at least one physical channel A baseband signal representing a physical uplink shared channel may perform one or more functions. The one or more functions may comprise at least one of: scrambling (e.g., by Scrambling); modulation of scrambled bits to generate complex-valued symbols (e.g., by a Modulation mapper); mapping of the complex-valued modulation symbols onto one or several transmission layers (e.g., by a Layer mapper); transform precoding to generate complex-valued symbols (e.g., by a Transform precoder); precoding of the complex-valued symbols (e.g., by a Precoder); mapping of precoded complex-valued symbols to resource elements (e.g., by a Resource element mapper); generation of complex-valued time-domain Single Carrier-Frequency Division Multiple Access (SC-FDMA) or CP-OFDM signal for an antenna port (e.g., by a signal gen.); and/or the like. A SC-FDMA signal for uplink transmission may be generated, for example, if transform precoding is enabled. A CP-OFDM signal for uplink transmission may be generated by FIG. **4**A, for example, if transform precoding is not enabled. These functions are shown as examples and other mechanisms may be implemented.

FIG. **4**B shows an example of modulation and up-conversion to the carrier frequency of a complex-valued SC-FDMA or CP-OFDM baseband signal for an antenna port and/or for the complex-valued Physical Random Access Channel (PRACH) baseband signal. Filtering may be performed prior to transmission.

FIG. **4**C shows an example of downlink transmissions. The baseband signal representing a downlink physical channel may perform one or more functions. The one or more functions may comprise: scrambling of coded bits in a codeword to be transmitted on a physical channel (e.g., by Scrambling); modulation of scrambled bits to generate complex-valued modulation symbols (e.g., by a Modulation mapper); mapping of the complex-valued modulation symbols onto one or several transmission layers (e.g., by a Layer mapper); precoding of the complex-valued modulation symbols on a layer for transmission on the antenna ports (e.g., by Precoding); mapping of complex-valued modulation symbols for an antenna port to resource elements (e.g., by a Resource element mapper); generation of complex-valued time-domain OFDM signal for an antenna port (e.g., by an OFDM signal gen.); and/or the like. These functions are shown as examples and other mechanisms may be implemented.

A base station may send (e.g., transmit) a first symbol and a second symbol on an antenna port, to a wireless device. The wireless device may infer the channel (e.g., fading gain, multipath delay, etc.) for conveying the second symbol on the antenna port, from the channel for conveying the first symbol on the antenna port. A first antenna port and a second antenna port may be quasi co-located, for example, if one or more large-scale properties of the channel over which a first symbol on the first antenna port is conveyed may be inferred from the channel over which a second symbol on a second antenna port is conveyed. The one or more large-scale properties may comprise at least one of: delay spread; Doppler spread; Doppler shift; average gain; average delay; and/or spatial receiving (Rx) parameters.

FIG. **4**D shows an example modulation and up-conversion to the carrier frequency of the complex-valued OFDM baseband signal for an antenna port. Filtering may be performed prior to transmission.

FIG. **5**A shows example uplink channel mapping and example uplink physical signals. A physical layer may provide one or more information transfer services to a MAC and/or one or more higher layers. The physical layer may provide the one or more information transfer services to the MAC via one or more transport channels. An information transfer service may indicate how and/or with what characteristics data is transferred over the radio interface.

Uplink transport channels may comprise an Uplink-Shared Channel (UL-SCH) **501** and/or a Random Access Channel (RACH) **502**. A wireless device may send (e.g., transmit) one or more uplink DM-RSs **506** to a base station for channel estimation, for example, for coherent demodulation of one or more uplink physical channels (e.g., PUSCH **503** and/or PUCCH **504**). The wireless device may send (e.g., transmit) to a base station at least one uplink DM-RS **506** with PUSCH **503** and/or PUCCH **504**, wherein the at least one uplink DM-RS **506** may be spanning a same frequency range as a corresponding physical channel. The base station may configure the wireless device with one or more uplink DM-RS configurations. At least one DM-RS configuration may support a front-loaded DM-RS pattern. A front-loaded DM-RS may be mapped over one or more OFDM symbols (e.g., 1 or 2 adjacent OFDM symbols). One or more additional uplink DM-RS may be configured to send (e.g., transmit) at one or more symbols of a PUSCH and/or PUCCH. The base station may semi-statically configure the wireless device with a maximum number of front-loaded DM-RS symbols for PUSCH and/or PUCCH. The wireless device may schedule a single-symbol DM-RS and/or double symbol DM-RS based on a maximum number of front-loaded DM-RS symbols, wherein the base station may configure the wireless device with one or more additional uplink DM-RS for PUSCH and/or PUCCH. A new radio network may support, for example, at least for CP-OFDM, a common DM-RS structure for DL and UL, wherein a DM-RS location, DM-RS pattern, and/or scrambling sequence may be same or different.

Whether or not an uplink PT-RS **507** is present may depend on an RRC configuration. A presence of the uplink PT-RS may be wireless device-specifically configured. A presence and/or a pattern of the uplink PT-RS **507** in a scheduled resource may be wireless device-specifically configured by a combination of RRC signaling and/or association with one or more parameters used for other purposes (e.g., Modulation and Coding Scheme (MCS)) which may be indicated by DCI. If configured, a dynamic presence of uplink PT-RS **507** may be associated with one or more DCI parameters comprising at least a MCS. A radio network may support a plurality of uplink PT-RS densities defined in time/frequency domain. If present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. A wireless device may assume a same precoding for a D-MRS port and a PT-RS port. A number of PT-RS ports may be less than a number of

DM-RS ports in a scheduled resource. The uplink PT-RS **507** may be confined in the scheduled time/frequency duration for a wireless device.

A wireless device may send (e.g., transmit) an SRS **508** to a base station for channel state estimation, for example, to support uplink channel dependent scheduling and/or link adaptation. The SRS **508** sent (e.g., transmitted) by the wireless device may allow for the base station to estimate an uplink channel state at one or more different frequencies. A base station scheduler may use an uplink channel state to assign one or more resource blocks of a certain quality (e.g., above a quality threshold) for an uplink PUSCH transmission from the wireless device. The base station may semi-statically configure the wireless device with one or more SRS resource sets. For an SRS resource set, the base station may configure the wireless device with one or more SRS resources. An SRS resource set applicability may be configured by a higher layer (e.g., RRC) parameter. An SRS resource in each of one or more SRS resource sets may be sent (e.g., transmitted) at a time instant, for example, if a higher layer parameter indicates beam management. The wireless device may send (e.g., transmit) one or more SRS resources in different SRS resource sets simultaneously. A new radio network may support aperiodic, periodic, and/or semi-persistent SRS transmissions. The wireless device may send (e.g., transmit) SRS resources, for example, based on one or more trigger types. The one or more trigger types may comprise higher layer signaling (e.g., RRC) and/or one or more DCI formats (e.g., at least one DCI format may be used for a wireless device to select at least one of one or more configured SRS resource sets). An SRS trigger type 0 may refer to an SRS triggered based on a higher layer signaling. An SRS trigger type 1 may refer to an SRS triggered based on one or more DCI formats. The wireless device may be configured to send (e.g., transmit) the SRS **508** after a transmission of PUSCH **503** and corresponding uplink DM-RS **506**, for example, if PUSCH **503** and the SRS **508** are transmitted in a same slot.

A base station may semi-statically configure a wireless device with one or more SRS configuration parameters indicating at least one of following: an SRS resource configuration identifier, a number of SRS ports, time domain behavior of SRS resource configuration (e.g., an indication of periodic, semi-persistent, or aperiodic SRS), slot (mini-slot, and/or subframe) level periodicity and/or offset for a periodic and/or aperiodic SRS resource, a number of OFDM symbols in a SRS resource, starting OFDM symbol of a SRS resource, an SRS bandwidth, a frequency hopping bandwidth, a cyclic shift, and/or an SRS sequence ID.

FIG. **5**B shows an example downlink channel mapping and downlink physical signals. Downlink transport channels may comprise a Downlink-Shared Channel (DL-SCH) **511**, a Paging Channel (PCH) **512**, and/or a Broadcast Channel (BCH) **513**. A transport channel may be mapped to one or more corresponding physical channels. A UL-SCH **501** may be mapped to a Physical Uplink Shared Channel (PUSCH) **503**. A RACH **502** may be mapped to a PRACH **505**. A DL-SCH **511** and a PCH **512** may be mapped to a Physical Downlink Shared Channel (PDSCH) **514**. A BCH **513** may be mapped to a Physical Broadcast Channel (PBCH) **516**.

A radio network may comprise one or more downlink and/or uplink transport channels. The radio network may comprise one or more physical channels without a corresponding transport channel. The one or more physical channels may be used for an Uplink Control Information (UCI) **509** and/or a Downlink Control Information (DCI) **517**. A Physical Uplink Control Channel (PUCCH) **504** may carry UCI **509** from a wireless device to a base station. A Physical Downlink Control Channel (PDCCH) **515** may carry the DCI **517** from a base station to a wireless device. The radio network (e.g., NR) may support the UCI **509** multiplexing in the PUSCH **503**, for example, if the UCI **509** and the PUSCH **503** transmissions may coincide in a slot (e.g., at least in part). The UCI **509** may comprise at least one of a CSI, an Acknowledgement (ACK)/Negative Acknowledgement (NACK), and/or a scheduling request. The DCI **517** via the PDCCH **515** may indicate at least one of following: one or more downlink assignments and/or one or more uplink scheduling grants.

In uplink, a wireless device may send (e.g., transmit) one or more Reference Signals (RSs) to a base station. The one or more RSs may comprise at least one of a Demodulation-RS (DM-RS) **506**, a Phase Tracking-RS (PT-RS) **507**, and/or a Sounding RS (SRS) **508**. In downlink, a base station may send (e.g., transmit, unicast, multicast, and/or broadcast) one or more RSs to a wireless device. The one or more RSs may comprise at least one of a Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS) **521**, a CSI-RS **522**, a DM-RS **523**, and/or a PT-RS **524**.

In a time domain, an SS/PBCH block may comprise one or more OFDM symbols (e.g., 4 OFDM symbols numbered in increasing order from 0 to 3) within the SS/PBCH block. An SS/PBCH block may comprise the PSS/SSS **521** and/or the PBCH **516**. In the frequency domain, an SS/PBCH block may comprise one or more contiguous subcarriers (e.g., 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239) within the SS/PBCH block. The PSS/SSS **521** may occupy, for example, 1 OFDM symbol and 127 subcarriers. The PBCH **516** may span across, for example, 3 OFDM symbols and 240 subcarriers. A wireless device may assume that one or more SS/PBCH blocks transmitted with a same block index may be quasi co-located, for example, with respect to Doppler spread, Doppler shift, average gain, average delay, and/or spatial Rx parameters. A wireless device may not assume quasi co-location for other SS/PBCH block transmissions. A periodicity of an SS/PBCH block may be configured by a radio network (e.g., by an RRC signaling). One or more time locations in which the SS/PBCH block may be sent may be determined by sub-carrier spacing. A wireless device may assume a band-specific sub-carrier spacing for an SS/PBCH block, for example, unless a radio network has configured the wireless device to assume a different sub-carrier spacing.

The downlink CSI-RS **522** may be used for a wireless device to acquire channel state information. A radio network may support periodic, aperiodic, and/or semi-persistent transmission of the downlink CSI-RS **522**. A base station may semi-statically configure and/or reconfigure a wireless device with periodic transmission of the downlink CSI-RS **522**. A configured CSI-RS resources may be activated and/or deactivated. For semi-persistent transmission, an activation and/or deactivation of a CSI-RS resource may be triggered dynamically. A CSI-RS configuration may comprise one or more parameters indicating at least a number of antenna ports. A base station may configure a wireless device with 32 ports, or any other number of ports. A base station may semi-statically configure a wireless device with one or more CSI-RS resource sets. One or more CSI-RS resources may be allocated from one or more CSI-RS resource sets to one or more wireless devices. A base station may semi-statically configure one or more parameters indicating CSI RS resource mapping, for example, time-domain location of one or more CSI-RS resources, a bandwidth of a CSI-RS resource, and/or a periodicity. A wireless device may be configured to use the same OFDM symbols for the downlink CSI-RS **522** and the Control Resource Set (CORESET), for example, if the downlink CSI-RS **522** and the CORESET are spatially quasi co-located and resource elements associated with the downlink CSI-RS **522** are the outside of PRBs configured for the CORESET. A wireless device may be configured to use the same OFDM symbols for downlink CSI-RS **522** and SS/PBCH blocks, for example, if the downlink CSI-RS **522** and SS/PBCH blocks are spatially quasi co-located and resource elements associated with the downlink CSI-RS **522** are outside of the PRBs configured for the SS/PBCH blocks.

A wireless device may send (e.g., transmit) one or more downlink DM-RSs **523** to a base station for channel estimation, for example, for coherent demodulation of one or more downlink physical channels (e.g., PDSCH **514**). A radio network may support one or more variable and/or configurable DM-RS patterns for data demodulation. At least one downlink DM-RS configuration may support a front-loaded DM-RS pattern. A front-loaded DM-RS may be mapped over one or more OFDM symbols (e.g., 1 or 2 adjacent OFDM symbols). A base station may semi-statically configure a wireless device with a maximum number of front-loaded DM-RS symbols for PDSCH **514**. A DM-RS configuration may support one or more DM-RS ports. A DM-RS configuration may support at least 8 orthogonal downlink DM-RS ports, for example, for single user-MIMO. ADM-RS configuration may support 12 orthogonal downlink DM-RS ports, for example, for multiuser-MIMO. A radio network may support, for example, at least for CP-OFDM, a common DM-RS structure for DL and UL, wherein a DM-RS location, DM-RS pattern, and/or scrambling sequence may be the same or different.

Whether or not the downlink PT-RS **524** is present may depend on an RRC configuration. A presence of the downlink PT-RS **524** may be wireless device-specifically configured. A presence and/or a pattern of the downlink PT-RS **524** in a scheduled resource may be wireless device-specifically configured, for example, by a combination of RRC signaling and/or an association with one or more parameters used for other purposes (e.g., MCS) which may be indicated by the DCI. If configured, a dynamic presence of the downlink PT-RS **524** may be associated with one or more DCI parameters comprising at least MCS. A radio network may support a plurality of PT-RS densities in a time/frequency domain. If present, a frequency domain density may be associated with at least one configuration of a scheduled bandwidth. A wireless device may assume the same precoding for a DM-RS port and a PT-RS port. A number of PT-RS ports may be less than a number of DM-RS ports in a scheduled resource. The downlink PT-RS **524** may be confined in the scheduled time/frequency duration for a wireless device.

FIG. **6** shows an example transmission time and reception time for a carrier. A multicarrier OFDM communication system may include one or more carriers, for example, ranging from 1 to 32 carriers (such as for carrier aggregation) or ranging from 1 to 64 carriers (such as for dual connectivity). Different radio frame structures may be supported (e.g., for FDD and/or for TDD duplex mechanisms). FIG. **6** shows an example frame timing. Downlink and uplink transmissions may be organized into radio frames **601**. Radio frame duration may be 10 milliseconds (ms). A 10 ms radio frame **601** may be divided into ten equally sized subframes **602**, each with a 1 ms duration. Subframe(s) may comprise one or more slots (e.g., slots **603** and **605**) depending on subcarrier spacing and/or CP length. For example, a subframe with 15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz and 480 kHz subcarrier spacing may comprise one, two, four, eight, sixteen and thirty-two slots, respectively. In FIG. **6**, a subframe may be divided into two equally sized slots **603** with 0.5 ms duration. For example, 10 subframes may be available for downlink transmission and 10 subframes may be available for uplink transmissions in a 10 ms interval. Other subframe durations such as, for example, 0.5 ms, 1 ms, 2 ms, and 5 ms may be supported. Uplink and downlink transmissions may be separated in the frequency domain. Slot(s) may include a plurality of OFDM symbols **604**. The number of OFDM symbols **604** in a slot **605** may depend on the cyclic prefix length. A slot may be 14 OFDM symbols for the same subcarrier spacing of up to 480 kHz with normal CP. A slot may be 12 OFDM symbols for the same subcarrier spacing of 60 kHz with extended CP. A slot may comprise downlink, uplink, and/or a downlink part and an uplink part, and/or alike.

FIG. **7**A shows example sets of OFDM subcarriers. A base station may communicate with a wireless device using a carrier having an example channel bandwidth **700**. Arrow(s) in the example may depict a subcarrier in a multicarrier OFDM system. The OFDM system may use technology such as OFDM technology, SC-FDMA technology, and/or the like. An arrow **701** shows a subcarrier transmitting information symbols. A subcarrier spacing **702**, between two contiguous subcarriers in a carrier, may be any one of 15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz, or any other frequency. Different subcarrier spacing may correspond to different transmission numerologies. A transmission numerology may comprise at least: a numerology index; a value of subcarrier spacing; and/or a type of cyclic prefix (CP). A base station may send (e.g., transmit) to and/or receive from a wireless device via a number of subcarriers **703** in a carrier. A bandwidth occupied by a number of subcarriers **703** (e.g., transmission bandwidth) may be smaller than the channel bandwidth **700** of a carrier, for example, due to guard bands **704** and **705**. Guard bands **704** and **705** may be used to reduce interference to and from one or more neighbor carriers. A number of subcarriers (e.g., transmission bandwidth) in a carrier may depend on the channel bandwidth of the carrier and/or the subcarrier spacing. A transmission bandwidth, for a carrier with a 20 MHz channel bandwidth and a 15 kHz subcarrier spacing, may be in number of 1024 subcarriers.

A base station and a wireless device may communicate with multiple component carriers (CCs), for example, if configured with CA. Different component carriers may have different bandwidth and/or different subcarrier spacing, for example, if CA is supported. A base station may send (e.g., transmit) a first type of service to a wireless device via a first component carrier. The base station may send (e.g., transmit) a second type of service to the wireless device via a second component carrier. Different types of services may have different service requirements (e.g., data rate, latency, reliability), which may be suitable for transmission via different component carriers having different subcarrier spacing and/or different bandwidth.

FIG. **7**B shows examples of component carriers. A first component carrier may comprise a first number of subcarriers **706** having a first subcarrier spacing **709**. A second component carrier may comprise a second number of subcarriers **707** having a second subcarrier spacing **710**. A third component carrier may comprise a third number of subcarriers **708** having a third subcarrier spacing **711**. Carriers in a multicarrier OFDM communication system may be contiguous carriers, non-contiguous carriers, or a combination of both contiguous and non-contiguous carriers.

FIG. **8** shows an example of OFDM radio resources. A carrier may have a transmission bandwidth **801**. A resource grid may be in a structure of frequency domain **802** and time domain **803**. A resource grid may comprise a first number of OFDM symbols in a subframe and a second number of resource blocks, starting from a common resource block indicated by higher-layer signaling (e.g., RRC signaling), for a transmission numerology and a carrier. In a resource grid, a resource element **805** may comprise a resource unit that may be identified by a subcarrier index and a symbol index. A subframe may comprise a first number of OFDM symbols **807** that may depend on a numerology associated with a carrier. A subframe may have 14 OFDM symbols for a carrier, for example, if a subcarrier spacing of a numerology of a carrier is 15 kHz. A subframe may have 28 OFDM symbols, for example, if a subcarrier spacing of a numerology is 30 kHz. A subframe may have 56 OFDM symbols, for example, if a subcarrier spacing of a numerology is 60 kHz. A subcarrier spacing of a numerology may comprise any other frequency. A second number of resource blocks comprised in a resource grid of a carrier may depend on a bandwidth and a numerology of the carrier.

A resource block **806** may comprise 12 subcarriers. Multiple resource blocks may be grouped into a Resource Block Group (RBG) **804**. A size of a RBG may depend on at least one of: a RRC message indicating a RBG size configuration; a size of a carrier bandwidth; and/or a size of a bandwidth part of a carrier. A carrier may comprise multiple bandwidth parts. A first bandwidth part of a carrier may have a different frequency location and/or a different bandwidth from a second bandwidth part of the carrier.

A base station may send (e.g., transmit), to a wireless device, a downlink control information comprising a downlink or uplink resource block assignment. A base station may send (e.g., transmit) to and/or receive from, a wireless device, data packets (e.g., transport blocks). The data packets may be scheduled on and transmitted via one or more resource blocks and one or more slots indicated by parameters in downlink control information and/or RRC message(s). A starting symbol relative to a first slot of the one or more slots may be indicated to the wireless device. A base station may send (e.g., transmit) to and/or receive from, a wireless device, data packets. The data packets may be scheduled for transmission on one or more RBGs and in one or more slots.

A base station may send (e.g., transmit), to a wireless device, downlink control information comprising a downlink assignment. The base station may send (e.g., transmit) the DCI via one or more PDCCHs. The downlink assignment may comprise parameters indicating at least one of a modulation and coding format; resource allocation; and/or HARQ information related to the DL-SCH. The resource allocation may comprise parameters of resource block allocation; and/or slot allocation. A base station may allocate (e.g., dynamically) resources to a wireless device, for example, via a Cell-Radio Network Temporary Identifier (C-RNTI) on one or more PDCCHs. The wireless device may monitor the one or more PDCCHs, for example, in order to find possible allocation if its downlink reception is enabled. The wireless device may receive one or more downlink data packets on one or more PDSCH scheduled by the one or more PDCCHs, for example, if the wireless device successfully detects the one or more PDCCHs.

A base station may allocate Configured Scheduling (CS) resources for down link transmission to a wireless device. The base station may send (e.g., transmit) one or more RRC messages indicating a periodicity of the CS grant. The base station may send (e.g., transmit) DCI via a PDCCH addressed to a Configured Scheduling-RNTI (CS-RNTI) activating the CS resources. The DCI may comprise parameters indicating that the downlink grant is a CS grant. The CS grant may be implicitly reused according to the periodicity defined by the one or more RRC messages. The CS grant may be implicitly reused, for example, until deactivated.

A base station may send (e.g., transmit), to a wireless device via one or more PDCCHs, downlink control information comprising an uplink grant. The uplink grant may comprise parameters indicating at least one of a modulation and coding format; a resource allocation; and/or HARQ information related to the UL-SCH. The resource allocation may comprise parameters of resource block allocation; and/or slot allocation. The base station may dynamically allocate resources to the wireless device via a C-RNTI on one or more PDCCHs. The wireless device may monitor the one or more PDCCHs, for example, in order to find possible resource allocation. The wireless device may send (e.g., transmit) one or more uplink data packets via one or more PUSCH scheduled by the one or more PDCCHs, for example, if the wireless device successfully detects the one or more PDCCHs.

The base station may allocate CS resources for uplink data transmission to a wireless device. The base station may transmit one or more RRC messages indicating a periodicity of the CS grant. The base station may send (e.g., transmit) DCI via a PDCCH addressed to a CS-RNTI to activate the CS resources. The DCI may comprise parameters indicating that the uplink grant is a CS grant. The CS grant may be implicitly reused according to the periodicity defined by the one or more RRC message, The CS grant may be implicitly reused, for example, until deactivated.

A base station may send (e.g., transmit) DCI and/or control signaling via a PDCCH. The DCI may comprise a format of a plurality of formats. The DCI may comprise downlink and/or uplink scheduling information (e.g., resource allocation information, HARQ related parameters, MCS), request(s) for CSI (e.g., aperiodic CQI reports), request(s) for an SRS, uplink power control commands for one or more cells, one or more timing information (e.g., TB transmission/reception timing, HARQ feedback timing, etc.), and/or the like. The DCI may indicate an uplink grant comprising transmission parameters for one or more transport blocks. The DCI may indicate a downlink assignment indicating parameters for receiving one or more transport blocks. The DCI may be used by the base station to initiate a contention-free random access at the wireless device. The base station may send (e.g., transmit) DCI comprising a slot format indicator (SFI) indicating a slot format. The base station may send (e.g., transmit) DCI comprising a pre-emption indication indicating the PRB(s) and/or OFDM symbol(s) in which a wireless device may assume no transmission is intended for the wireless device. The base station may send (e.g., transmit) DCI for group power control of the PUCCH, the PUSCH, and/or an SRS. DCI may correspond to an RNTI. The wireless device may obtain an RNTI after or in response to completing the initial access (e.g., C-RNTI). The base station may configure an RNTI for the wireless (e.g., CS-RNTI, TPC-CS-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, TPC-SRS-RNTI, etc.). The wireless device may determine (e.g., compute) an RNTI (e.g., the wireless device may determine the RA-RNTI based on resources used for transmission of a preamble). An RNTI may have a pre-configured value (e.g., P-RNTI or SI-RNTI). The wireless device may monitor a group common search space which may be used by the base station for sending (e.g., transmitting) DCIs that are intended for a group of wireless devices. A group common DCI may correspond to an RNTI which is commonly configured for a group of wireless devices. The wireless device may monitor a wireless device-specific search space. A wireless device specific DCI may correspond to an RNTI configured for the wireless device.

A communications system (e.g., an NR system) may support a single beam operation and/or a multi-beam operation. In a multi-beam operation, a base station may perform a downlink beam sweeping to provide coverage for common control channels and/or downlink SS blocks, which may comprise at least a PSS, a SSS, and/or PBCH. A wireless device may measure quality of a beam pair link using one or more RSs. One or more SS blocks, or one or more CSI-RS resources (e.g., which may be associated with a CSI-RS resource index (CRI)), and/or one or more DM-RSs of a PBCH, may be used as an RS for measuring a quality of a beam pair link. The quality of a beam pair link may be based on a reference signal received power (RSRP) value, a reference signal received quality (RSRQ) value, and/or a CSI value measured on RS resources. The base station may indicate whether an RS resource, used for measuring a beam pair link quality, is quasi-co-located (QCLed) with DM-RSs of a control channel. An RS resource and DM-RSs of a control channel may be called QCLed, for example, if channel characteristics from a transmission on an RS to a wireless device, and that from a transmission on a control channel to a wireless device, are similar or the same under a configured criterion. In a multi-beam operation, a wireless device may perform an uplink beam sweeping to access a cell.

A wireless device may be configured to monitor a PDCCH on one or more beam pair links simultaneously, for example, depending on a capability of the wireless device. This monitoring may increase robustness against beam pair link blocking. A base station may send (e.g., transmit) one or more messages to configure the wireless device to monitor the PDCCH on one or more beam pair links in different PDCCH OFDM symbols. A base station may send (e.g., transmit) higher layer signaling (e.g., RRC signaling) and/or a MAC CE comprising parameters related to the Rx beam setting of the wireless device for monitoring the PDCCH on one or more beam pair links. The base station may send (e.g., transmit) an indication of a spatial QCL assumption between an DL RS antenna port(s) (e.g., a cell-specific CSI-RS, a wireless device-specific CSI-RS, an SS block, and/or a PBCH with or without DM-RSs of the PBCH) and/or DL RS antenna port(s) for demodulation of a DL control channel. Signaling for beam indication for a PDCCH may comprise MAC CE signaling, RRC signaling, DCI signaling, and/or specification-transparent and/or implicit method, and/or any combination of signaling methods.

A base station may indicate spatial QCL parameters between DL RS antenna port(s) and DM-RS antenna port(s) of a DL data channel, for example, for reception of a unicast DL data channel. The base station may send (e.g., transmit) DCI (e.g., downlink grants) comprising information indicating the RS antenna port(s). The information may indicate RS antenna port(s) that may be QCL-ed with the DM-RS antenna port(s). A different set of DM-RS antenna port(s) for a DL data channel may be indicated as QCL with a different set of the RS antenna port(s).

FIG. **9**A shows an example of beam sweeping in a DL channel. In an RRC_INACTIVE state or RRC_IDLE state, a wireless device may assume that SS blocks form an SS burst **940**, and an SS burst set **950**. The SS burst set **950** may have a given periodicity. A base station **120** may send (e.g., transmit) SS blocks in multiple beams, together forming an SS burst **940**, for example, in a multi-beam operation. One or more SS blocks may be sent (e.g., transmitted) on one beam. If multiple SS bursts **940** are transmitted with multiple beams, the SS bursts **940** together may form the SS burst set **950**.

A wireless device may use CSI-RS for estimating a beam quality of a link between a wireless device and a base station, for example, in the multi beam operation. A beam may be associated with a CSI-RS. A wireless device may (e.g., based on a RSRP measurement on CSI-RS) report a beam index, which may be indicated in a CRI for downlink beam selection and/or associated with an RSRP value of a beam. A CSI-RS may be sent (e.g., transmitted) on a CSI-RS resource, which may comprise at least one of: one or more antenna ports and/or one or more time and/or frequency radio resources. A CSI-RS resource may be configured in a cell-specific way such as by common RRC signaling, or in a wireless device-specific way such as by dedicated RRC signaling and/or L1/L2 signaling. Multiple wireless devices covered by a cell may measure a cell-specific CSI-RS resource. A dedicated subset of wireless devices covered by a cell may measure a wireless device-specific CSI-RS resource.

A CSI-RS resource may be sent (e.g., transmitted) periodically, using aperiodic transmission, or using a multi-shot or semi-persistent transmission. In a periodic transmission in FIG. **9**A, a base station **120** may send (e.g., transmit) configured CSI-RS resources **940** periodically using a configured periodicity in a time domain. In an aperiodic transmission, a configured CSI-RS resource may be sent (e.g., transmitted) in a dedicated time slot. In a multi-shot and/or semi-persistent transmission, a configured CSI-RS resource may be sent (e.g., transmitted) within a configured period. Beams used for CSI-RS transmission may have a different beam width than beams used for SS-blocks transmission.

FIG. **9**B shows an example of a beam management procedure, such as new radio network. The base station **120** and/or the wireless device **110** may perform a downlink L1/L2 beam management procedure. One or more of the following downlink L1/L2 beam management procedures may be performed within one or more wireless devices **110** and one or more base stations **120**. A P1 procedure **910** may be used to enable the wireless device **110** to measure one or more Transmission (Tx) beams associated with the base station **120**, for example, to support a selection of a first set of Tx beams associated with the base station **120** and a first set of Rx beam(s) associated with the wireless device **110**. A base station **120** may sweep a set of different Tx beams, for example, for beamforming at a base station **120** (such as shown in the top row, in a counter-clockwise direction). A wireless device **110** may sweep a set of different Rx beams, for example, for beamforming at a wireless device **110** (such as shown in the bottom row, in a clockwise direction). A P2 procedure **920** may be used to enable a wireless device **110** to measure one or more Tx beams associated with a base station **120**, for example, to possibly change a first set of Tx beams associated with a base station **120**. A P2 procedure **920** may be performed on a possibly smaller set of beams (e.g., for beam refinement) than in the P1 procedure **910**. A P2 procedure **920** may be a special example of a P1 procedure **910**. A P3 procedure **930** may be used to enable a wireless device **110** to measure at least one Tx beam associated with a base station **120**, for example, to change a first set of Rx beams associated with a wireless device **110**.

A wireless device **110** may send (e.g., transmit) one or more beam management reports to a base station **120**. In one or more beam management reports, a wireless device **110** may indicate one or more beam pair quality parameters comprising one or more of: a beam identification; an RSRP; a Precoding Matrix Indicator (PMI), Channel Quality Indicator (CQI), and/or Rank Indicator (RI) of a subset of configured beams. Based on one or more beam management reports, the base station **120** may send (e.g., transmit) to a wireless device **110** a signal indicating that one or more beam pair links are one or more serving beams. The base station **120** may send (e.g., transmit) the PDCCH and the PDSCH for a wireless device **110** using one or more serving beams.

A communications network (e.g., a new radio network) may support a Bandwidth Adaptation (BA). Receive and/or transmit bandwidths that may be configured for a wireless device using a BA may not be large. Receive and/or transmit bandwidth may not be as large as a bandwidth of a cell. Receive and/or transmit bandwidths may be adjustable. A wireless device may change receive and/or transmit bandwidths, for example, to reduce (e.g., shrink) the bandwidth(s) at (e.g., during) a period of low activity such as to save power. A wireless device may change a location of receive and/or transmit bandwidths in a frequency domain, for example, to increase scheduling flexibility. A wireless device may change a subcarrier spacing, for example, to allow different services.

A Bandwidth Part (BWP) may comprise a subset of a total cell bandwidth of a cell. A base station may configure a wireless device with one or more BWPs, for example, to achieve a BA. A base station may indicate, to a wireless device, which of the one or more (configured) BWPs is an active BWP.

FIG. **10** shows an example of BWP configurations. BWPs may be configured as follows: BWP**1** (**1010** and **1050**) with a width of 40 MHz and subcarrier spacing of 15 kHz; BWP**2** (**1020** and **1040**) with a width of 10 MHz and subcarrier spacing of 15 kHz; BWP**3** **1030** with a width of 20 MHz and subcarrier spacing of 60 kHz. Any number of BWP configurations may comprise any other width and subcarrier spacing combination.

A wireless device, configured for operation in one or more BWPs of a cell, may be configured by one or more higher layers (e.g., RRC layer). The wireless device may be configured for a cell with: a set of one or more BWPs (e.g., at most four BWPs) for reception (e.g., a DL BWP set) in a DL bandwidth by at least one parameter DL-BWP; and a set of one or more BWPs (e.g., at most four BWPs) for transmissions (e.g., UL BWP set) in an UL bandwidth by at least one parameter UL-BWP. BWPs are described as example resources. Any wireless resource may be applicable to one or more procedures described herein.

A base station may configure a wireless device with one or more UL and DL BWP pairs, for example, to enable BA on the Pcell. To enable BA on Scells (e.g., for CA), a base station may configure a wireless device at least with one or more DL BWPs (e.g., there may be none in an UL).

An initial active DL BWP may comprise at least one of a location and number of contiguous PRBs, a subcarrier spacing, or a cyclic prefix, for example, for a control resource set for at least one common search space. For operation on the Pcell, one or more higher layer parameters may indicate at least one initial UL BWP for a random access procedure. If a wireless device is configured with a secondary carrier on a primary cell, the wireless device may be configured with an initial BWP for random access procedure on a secondary carrier.

A wireless device may expect that a center frequency for a DL BWP may be same as a center frequency for a UL BWP, for example, for unpaired spectrum operation. A base station may semi-statically configure a wireless device for a cell with one or more parameters, for example, for a DL BWP or an UL BWP in a set of one or more DL BWPs or one or more UL BWPs, respectively. The one or more parameters may indicate one or more of following: a subcarrier spacing; a cyclic prefix; a number of contiguous PRBs; an index in the set of one or more DL BWPs and/or one or more UL BWPs; a link between a DL BWP and an UL BWP from a set of configured DL BWPs and UL BWPs; a DCI detection to a PDSCH reception timing; a PDSCH reception to a HARQ-ACK transmission timing value; a DCI detection to a PUSCH transmission timing value; and/or an offset of a first PRB of a DL bandwidth or an UL bandwidth, respectively, relative to a first PRB of a bandwidth.

For a DL BWP in a set of one or more DL BWPs on a Pcell, a base station may configure a wireless device with one or more control resource sets for at least one type of common search space and/or one wireless device-specific search space. A base station may refrain from configuring a wireless device without a common search space on a Pcell, or on a PSCell, in an active DL BWP. For an UL BWP in a set of one or more UL BWPs, a base station may configure a wireless device with one or more resource sets for one or more PUCCH transmissions.

DCI may comprise a BWP indicator field. The BWP indicator field value may indicate an active DL BWP, from a configured DL BWP set, for one or more DL receptions. The BWP indicator field value may indicate an active UL BWP, from a configured UL BWP set, for one or more UL transmissions.

For a Pcell, a base station may semi-statically configure a wireless device with a default DL BWP among configured DL BWPs. If a wireless device is not provided with a default DL BWP, a default BWP may be an initial active DL BWP. A default BWP may not be configured for one or more wireless devices. A first (or initial) BWP may serve as a default BWP, for example, if a default BWP is not configured.

A base station may configure a wireless device with a timer value for a Pcell. A wireless device may start a timer (e.g., a BWP inactivity timer), for example, if a wireless device detects DCI indicating an active DL BWP, other than a default DL BWP, for a paired spectrum operation, and/or if a wireless device detects DCI indicating an active DL BWP or UL BWP, other than a default DL BWP or UL BWP, for an unpaired spectrum operation. The wireless device may increment the timer by an interval of a first value (e.g., the first value may be 1 millisecond, 0.5 milliseconds, or any other time duration), for example, if the wireless device does not detect DCI at (e.g., during) the interval for a paired spectrum operation or for an unpaired spectrum operation. The timer may expire at a time that the timer is equal to the timer value. A wireless device may switch to the default DL BWP from an active DL BWP, for example, if the timer expires.

A base station may semi-statically configure a wireless device with one or more BWPs. A wireless device may switch an active BWP from a first BWP to a second BWP, for example, after or in response to receiving DCI indicating the second BWP as an active BWP, and/or after or in response to an expiry of BWP inactivity timer (e.g., the second BWP may be a default BWP). FIG. **10** shows an example of three BWPs configured, BWP**1** (**1010** and **1050**), BWP**2** (**1020** and **1040**), and BWP**3** (**1030**). BWP**2** (**1020** and **1040**) may be a default BWP. BWP**1** (**1010**) may be an initial active BWP. A wireless device may switch an active BWP from BWP**1** **1010** to BWP**2** **1020**, for example, after or in response to an expiry of the BWP inactivity timer. A wireless device may switch an active BWP from BWP**2** **1020** to BWP**3** **1030**, for example, after or in response to receiving DCI indicating BWP**3** **1030** as an active BWP. Switching an active BWP from BWP**3** **1030** to BWP**2** **1040** and/or from BWP**2** **1040** to BWP**1** **1050** may be after or in response to receiving DCI indicating an active BWP, and/or after or in response to an expiry of BWP inactivity timer.

Wireless device procedures on a secondary cell may be same as on a primary cell using the timer value for the secondary cell and the default DL BWP for the secondary cell, for example, if a wireless device is configured for a secondary cell with a default DL BWP among configured DL BWPs and a timer value. A wireless device may use an indicated DL BWP and an indicated UL BWP on a secondary cell as a respective first active DL BWP and first active UL BWP on a secondary cell or carrier, for example, if a base station configures a wireless device with a first active DL BWP and a first active UL BWP on a secondary cell or carrier.

FIG. **11**A and FIG. **11**B show packet flows using a multi connectivity (e.g., dual connectivity, multi connectivity, tight interworking, and/or the like). FIG. **11**A shows an example of a protocol structure of a wireless device **110** (e.g., UE) with CA and/or multi connectivity. FIG. **11**B shows an example of a protocol structure of multiple base stations with CA and/or multi connectivity. The multiple base stations may comprise a master node, MN **1130** (e.g., a master node, a master base station, a master gNB, a master eNB, and/or the like) and a secondary node, SN **1150** (e.g., a secondary node, a secondary base station, a secondary gNB, a secondary eNB, and/or the like). A master node **1130** and a secondary node **1150** may co-work to communicate with a wireless device **110**.

If multi connectivity is configured for a wireless device **110**, the wireless device **110**, which may support multiple reception and/or transmission functions in an RRC connected state, may be configured to utilize radio resources provided by multiple schedulers of a multiple base stations. Multiple base stations may be inter-connected via a non-ideal or ideal backhaul (e.g., Xn interface, X2 interface, and/or the like). A base station involved in multi connectivity for a certain wireless device may perform at least one of two different roles: a base station may act as a master base station or act as a secondary base station. In multi connectivity, a wireless device may be connected to one master base station and one or more secondary base stations. A master base station (e.g., the MN **1130**) may provide a master cell group (MCG) comprising a primary cell and/or one or more secondary cells for a wireless device (e.g., the wireless device **110**). A secondary base station (e.g., the SN **1150**) may provide a secondary cell group (SCG) comprising a primary secondary cell (PSCell) and/or one or more secondary cells for a wireless device (e.g., the wireless device **110**).

In multi connectivity, a radio protocol architecture that a bearer uses may depend on how a bearer is setup. Three different types of bearer setup options may be supported: an MCG bearer, an SCG bearer, and/or a split bearer. A wireless device may receive and/or send (e.g., transmit) packets of an MCG bearer via one or more cells of the MCG. A wireless device may receive and/or send (e.g., transmit) packets of an SCG bearer via one or more cells of an SCG. Multi-connectivity may indicate having at least one bearer configured to use radio resources provided by the secondary base station. Multi-connectivity may or may not be configured and/or implemented.

A wireless device (e.g., wireless device **110**) may send (e.g., transmit) and/or receive: packets of an MCG bearer via an SDAP layer (e.g., SDAP **1110**), a PDCP layer (e.g., NR PDCP **1111**), an RLC layer (e.g., MN RLC **1114**), and a MAC layer (e.g., MN MAC **1118**); packets of a split bearer via an SDAP layer (e.g., SDAP **1110**), a PDCP layer (e.g., NR PDCP **1112**), one of a master or secondary RLC layer (e.g., MN RLC **1115**, SN RLC **1116**), and one of a master or secondary MAC layer (e.g., MN MAC **1118**, SN MAC **1119**); and/or packets of an SCG bearer via an SDAP layer (e.g., SDAP **1110**), a PDCP layer (e.g., NR PDCP **1113**), an RLC layer (e.g., SN RLC **1117**), and a MAC layer (e.g., MN MAC **1119**).

A master base station (e.g., MN **1130**) and/or a secondary base station (e.g., SN **1150**) may send (e.g., transmit) and/or receive: packets of an MCG bearer via a master or secondary node SDAP layer (e.g., SDAP **1120**, SDAP **1140**), a master or secondary node PDCP layer (e.g., NR PDCP **1121**, NR PDCP **1142**), a master node RLC layer (e.g., MN RLC **1124**, MN RLC **1125**), and a master node MAC layer (e.g., MN MAC **1128**); packets of an SCG bearer via a master or secondary node SDAP layer (e.g., SDAP **1120**, SDAP **1140**), a master or secondary node PDCP layer (e.g., NR PDCP **1122**, NR PDCP **1143**), a secondary node RLC layer (e.g., SN RLC **1146**, SN RLC **1147**), and a secondary node MAC layer (e.g., SN MAC **1148**); packets of a split bearer via a master or secondary node SDAP layer (e.g., SDAP **1120**, SDAP **1140**), a master or secondary node PDCP layer (e.g., NR PDCP **1123**, NR PDCP **1141**), a master or secondary node RLC layer (e.g., MN RLC **1126**, SN RLC **1144**, SN RLC **1145**, MN RLC **1127**), and a master or secondary node MAC layer (e.g., MN MAC **1128**, SN MAC **1148**).

In multi connectivity, a wireless device may configure multiple MAC entities, such as one MAC entity (e.g., MN MAC **1118**) for a master base station, and other MAC entities (e.g., SN MAC **1119**) for a secondary base station. In multi-connectivity, a configured set of serving cells for a wireless device may comprise two subsets: an MCG comprising serving cells of a master base station, and SCGs comprising serving cells of a secondary base station. For an SCG, one or more of following configurations may be used. At least one cell of an SCG may have a configured UL CC and at least one cell of a SCG, named as primary secondary cell (e.g., PSCell, Pcell of SCg, Pcell), and may be configured with PUCCH resources. If an SCG is configured, there may be at least one SCG bearer or one split bearer. After or upon detection of a physical layer problem or a random access problem on a PSCell, or a number of NR RLC retransmissions has been reached associated with the SCG, or after or upon detection of an access problem on a PSCell associated with (e.g., during) a SCG addition or an SCG change: an RRC connection re-establishment procedure may not be triggered, UL transmissions towards cells of an SCG may be stopped, a master base station may be informed by a wireless device of a SCG failure type, a DL data transfer over a master base station may be maintained (e.g., for a split bearer). An NR RLC acknowledged mode (AM) bearer may be configured for a split bearer. A Pcell and/or a PSCell may not be de-activated. A PSCell may be changed with a SCG change procedure (e.g., with security key change and a RACH procedure). A bearer type change between a split bearer and a SCG bearer, and/or simultaneous configuration of a SCG and a split bearer, may or may not be supported.

With respect to interactions between a master base station and a secondary base stations for multi-connectivity, one or more of the following may be used. A master base station and/or a secondary base station may maintain Radio Resource Management (RRM) measurement configurations of a wireless device. A master base station may determine (e.g., based on received measurement reports, traffic conditions, and/or bearer types) to request a secondary base station to provide additional resources (e.g., serving cells) for a wireless device. After or upon receiving a request from a master base station, a secondary base station may create and/or modify a container that may result in a configuration of additional serving cells for a wireless device (or decide that the secondary base station has no resource available to do so). For a wireless device capability coordination, a master base station may provide (e.g., all or a part of) an AS configuration and wireless device capabilities to a secondary base station. A master base station and a secondary base station may exchange information about a wireless device configuration such as by using RRC containers (e.g., inter-node messages) carried via Xn messages. A secondary base station may initiate a reconfiguration of the secondary base station existing serving cells (e.g., PUCCH towards the secondary base station). A secondary base station may decide which cell is a PSCell within a SCG. A master base station may or may not change content of RRC configurations provided by a secondary base station. A master base station may provide recent (and/or the latest) measurement results for SCG cell(s), for example, if an SCG addition and/or an ScG Scell addition occurs. A master base station and secondary base stations may receive information of SFN and/or subframe offset of each other from an OAM and/or via an Xn interface (e.g., for a purpose of DRX alignment and/or identification of a measurement gap). Dedicated RRC signaling may be used for sending required system information of a cell as for CA, for example, if adding a new ScG Scell, except for an SFN acquired from an MIB of a PSCell of a SCG.

FIG. **12** shows an example of a random access procedure. One or more events may trigger a random access procedure. For example, one or more events may be at least one of following: initial access from RRC_IDLE, RRC connection re-establishment procedure, handover, DL or UL data arrival in (e.g., during) a state of RRC_CONNECTED (e.g., if UL synchronization status is non-synchronized), transition from RRC_Inactive, and/or request for other system information. A PDCCH order, a MAC entity, and/or a beam failure indication may initiate a random access procedure.

A random access procedure may comprise or be one of at least a contention based random access procedure and/or a contention free random access procedure. A contention based random access procedure may comprise one or more Msg **1 1220** transmissions, one or more Msg**2 1230** transmissions, one or more Msg**3 1240** transmissions, and contention resolution **1250**. A contention free random access procedure may comprise one or more Msg **1 1220** transmissions and one or more Msg**2 1230** transmissions. One or more of Msg **1 1220**, Msg **2 1230**, Msg **3 1240**, and/or contention resolution **1250** may be transmitted in the same step. A two-step random access procedure, for example, may comprise a first transmission (e.g., Msg A) and a second transmission (e.g., Msg B). The first transmission (e.g., Msg A) may comprise transmitting, by a wireless device (e.g., wireless device **110**) to a base station (e.g., base station **120**), one or more messages indicating an equivalent and/or similar contents of Msg**1 1220** and Msg**3 1240** of a four-step random access procedure. The second transmission (e.g., Msg B) may comprise transmitting, by the base station (e.g., base station **120**) to a wireless device (e.g., wireless device **110**) after or in response to the first message, one or more messages indicating an equivalent and/or similar content of Msg**2 1230** and contention resolution **1250** of a four-step random access procedure.

A base station may send (e.g., transmit, unicast, multicast, broadcast, etc.), to a wireless device, a RACH configuration **1210** via one or more beams. The RACH configuration **1210** may comprise one or more parameters indicating at least one of following: an available set of PRACH resources for a transmission of a random access preamble, initial preamble power (e.g., random access preamble initial received target power), an RSRP threshold for a selection of a SS block and corresponding PRACH resource, a power-ramping factor (e.g., random access preamble power ramping step), a random access preamble index, a maximum number of preamble transmissions, preamble group A and group B, a threshold (e.g., message size) to determine the groups of random access preambles, a set of one or more random access preambles for a system information request and corresponding PRACH resource(s) (e.g., if any), a set of one or more random access preambles for a beam failure recovery procedure and corresponding PRACH resource(s) (e.g., if any), a time window to monitor RA response(s), a time window to monitor response(s) on a beam failure recovery procedure, and/or a contention resolution timer.

The Msg**1 1220** may comprise one or more transmissions of a random access preamble. For a contention based random access procedure, a wireless device may select an SS block with an RSRP above the RSRP threshold. If random access preambles group B exists, a wireless device may select one or more random access preambles from a group A or a group B, for example, depending on a potential Msg**3 1240** size. If a random access preambles group B does not exist, a wireless device may select the one or more random access preambles from a group A. A wireless device may select a random access preamble index randomly (e.g., with equal probability or a normal distribution) from one or more random access preambles associated with a selected group. If a base station semi-statically configures a wireless device with an association between random access preambles and SS blocks, the wireless device may select a random access preamble index randomly with equal probability from one or more random access preambles associated with a selected SS block and a selected group.

A wireless device may initiate a contention free random access procedure, for example, based on a beam failure indication from a lower layer. A base station may semi-statically configure a wireless device with one or more contention free PRACH resources for a beam failure recovery procedure associated with at least one of SS blocks and/or CSI-RSs. A wireless device may select a random access preamble index corresponding to a selected SS block or a CSI-RS from a set of one or more random access preambles for a beam failure recovery procedure, for example, if at least one of the SS blocks with an RSRP above a first RSRP threshold amongst associated SS blocks is available, and/or if at least one of CSI-RSs with a RSRP above a second RSRP threshold amongst associated CSI-RSs is available.

A wireless device may receive, from a base station, a random access preamble index via PDCCH or RRC for a contention free random access procedure. The wireless device may select a random access preamble index, for example, if a base station does not configure a wireless device with at least one contention free PRACH resource associated with SS blocks or CSI-RS. The wireless device may select the at least one SS block and/or select a random access preamble corresponding to the at least one SS block, for example, if a base station configures the wireless device with one or more contention free PRACH resources associated with SS blocks and/or if at least one SS block with a RSRP above a first RSRP threshold amongst associated SS blocks is available. The wireless device may select the at least one CSI-RS and/or select a random access preamble corresponding to the at least one CSI-RS, for example, if a base station configures a wireless device with one or more contention free PRACH resources associated with CSI-RSs and/or if at least one CSI-RS with a RSRP above a second RSPR threshold amongst the associated CSI-RSs is available.

A wireless device may perform one or more Msg**1 1220** transmissions, for example, by sending (e.g., transmitting) the selected random access preamble. The wireless device may determine a PRACH occasion from one or more PRACH occasions corresponding to a selected SS block, for example, if the wireless device selects an SS block and is configured with an association between one or more PRACH occasions and/or one or more SS blocks. The wireless device may determine a PRACH occasion from one or more PRACH occasions corresponding to a selected CSI-RS, for example, if the wireless device selects a CSI-RS and is configured with an association between one or more PRACH occasions and one or more CSI-RSs. The wireless device may send (e.g., transmit), to a base station, a selected random access preamble via a selected PRACH occasions. The wireless device may determine a transmit power for a transmission of a selected random access preamble at least based on an initial preamble power and a power-ramping factor. The wireless device may determine an RA-RNTI associated with a selected PRACH occasion in which a selected random access preamble is sent (e.g., transmitted). The wireless device may not determine an RA-RNTI for a beam failure recovery procedure. The wireless device may determine an RA-RNTI at least based on an index of a first OFDM symbol, an index of a first slot of a selected PRACH occasions, and/or an uplink carrier index for a transmission of Msg**1 1220**.

A wireless device may receive, from a base station, a random access response, Msg **2 1230**. The wireless device may start a time window (e.g., ra-ResponseWindow) to monitor a random access response. For a beam failure recovery procedure, the base station may configure the wireless device with a different time window (e.g., bfr-ResponseWindow) to monitor response to on a beam failure recovery request. The wireless device may start a time window (e.g., ra-ResponseWindow or bfr-ResponseWindow) at a start of a first PDCCH occasion, for example, after a fixed duration of one or more symbols from an end of a preamble transmission. If the wireless device sends (e.g., transmits) multiple preambles, the wireless device may start a time window at a start of a first PDCCH occasion after a fixed duration of one or more symbols from an end of a first preamble transmission. The wireless device may monitor a PDCCH of a cell for at least one random access response identified by a RA-RNTI, or for at least one response to a beam failure recovery request identified by a C-RNTI, at a time that a timer for a time window is running.

A wireless device may determine that a reception of random access response is successful, for example, if at least one random access response comprises a random access preamble identifier corresponding to a random access preamble sent (e.g., transmitted) by the wireless device. The wireless device may determine that the contention free random access procedure is successfully completed, for example, if a reception of a random access response is successful. The wireless device may determine that a contention free random access procedure is successfully complete, for example, if a contention free random access procedure is triggered for a beam failure recovery request and if a PDCCH transmission is addressed to a C-RNTI. The wireless device may determine that the random access procedure is successfully completed, and may indicate a reception of an acknowledgement for a system information request to upper layers, for example, if at least one random access response comprises a random access preamble identifier. The wireless device may stop sending (e.g., transmitting) remaining preambles (if any) after or in response to a successful reception of a corresponding random access response, for example, if the wireless device has signaled multiple preamble transmissions.

The wireless device may perform one or more Msg **3 1240** transmissions, for example, after or in response to a successful reception of random access response (e.g., for a contention based random access procedure). The wireless device may adjust an uplink transmission timing, for example, based on a timing advanced command indicated by a random access response. The wireless device may send (e.g., transmit) one or more transport blocks, for example, based on an uplink grant indicated by a random access response. Subcarrier spacing for PUSCH transmission for Msg**3 1240** may be provided by at least one higher layer (e.g., RRC) parameter. The wireless device may send (e.g., transmit) a random access preamble via a PRACH, and Msg**3 1240** via PUSCH, on the same cell. A base station may indicate an UL BWP for a PUSCH transmission of Msg**3 1240** via system information block. The wireless device may use HARQ for a retransmission of Msg **3 1240**.

Multiple wireless devices may perform Msg **1 1220**, for example, by sending (e.g., transmitting) the same preamble to a base station. The multiple wireless devices may receive, from the base station, the same random access response comprising an identity (e.g., TC-RNTI). Contention resolution (e.g., comprising the wireless device **110** receiving contention resolution **1250**) may be used to increase the likelihood that a wireless device does not incorrectly use an identity of another wireless device. The contention resolution **1250** may be based on, for example, a C-RNTI on a PDCCH, and/or a wireless device contention resolution identity on a DL-SCH. If a base station assigns a C-RNTI to a wireless device, the wireless device may perform contention resolution (e.g., comprising receiving contention resolution **1250**), for example, based on a reception of a PDCCH transmission that is addressed to the C-RNTI. The wireless device may determine that contention resolution is successful, and/or that a random access procedure is successfully completed, for example, after or in response to detecting a C-RNTI on a PDCCH. If a wireless device has no valid C-RNTI, a contention resolution may be addressed by using a TC-RNTI. If a MAC PDU is successfully decoded and a MAC PDU comprises a wireless device contention resolution identity MAC CE that matches or otherwise corresponds with the CCCH SDU sent (e.g., transmitted) in Msg**3 1250**, the wireless device may determine that the contention resolution (e.g., comprising contention resolution **1250**) is successful and/or the wireless device may determine that the random access procedure is successfully completed.

FIG. **13** shows an example structure for MAC entities. A wireless device may be configured to operate in a multi-connectivity mode. A wireless device in RRC_CONNECTED with multiple Rx/Tx may be configured to utilize radio resources provided by multiple schedulers that may be located in a plurality of base stations. The plurality of base stations may be connected via a non-ideal or ideal backhaul over the Xn interface. A base station in a plurality of base stations may act as a master base station or as a secondary base station. A wireless device may be connected to and/or in communication with, for example, one master base station and one or more secondary base stations. A wireless device may be configured with multiple MAC entities, for example, one MAC entity for a master base station, and one or more other MAC entities for secondary base station(s). A configured set of serving cells for a wireless device may comprise two subsets: an MCG comprising serving cells of a master base station, and one or more SCGs comprising serving cells of a secondary base station(s). FIG. **13** shows an example structure for MAC entities in which a MCG and a SCG are configured for a wireless device.

At least one cell in a SCG may have a configured UL CC. A cell of the at least one cell may comprise a PSCell or a Pcell of a SCG, or a Pcell. A PSCell may be configured with PUCCH resources. There may be at least one SCG bearer, or one split bearer, for a SCG that is configured. After or upon detection of a physical layer problem or a random access problem on a PSCell, after or upon reaching a number of RLC retransmissions associated with the SCG, and/or after or upon detection of an access problem on a PSCell associated with (e.g., during) a SCG addition or a SCG change: an RRC connection re-establishment procedure may not be triggered, UL transmissions towards cells of a SCG may be stopped, and/or a master base station may be informed by a wireless device of a SCG failure type and DL data transfer over a master base station may be maintained.

A MAC sublayer may provide services such as data transfer and radio resource allocation to upper layers (e.g., **1310** or **1320**). A MAC sublayer may comprise a plurality of MAC entities (e.g., **1350** and **1360**). A MAC sublayer may provide data transfer services on logical channels. To accommodate different kinds of data transfer services, multiple types of logical channels may be defined. A logical channel may support transfer of a particular type of information. A logical channel type may be defined by what type of information (e.g., control or data) is transferred. BCCH, PCCH, CCCH and/or DCCH may be control channels, and DTCH may be a traffic channel. A first MAC entity (e.g., **1310**) may provide services on PCCH, BCCH, CCCH, DCCH, DTCH, and/or MAC control elements. A second MAC entity (e.g., **1320**) may provide services on BCCH, DCCH, DTCH, and/or MAC control elements.

A MAC sublayer may expect from a physical layer (e.g., **1330** or **1340**) services such as data transfer services, signaling of HARQ feedback, and/or signaling of scheduling request or measurements (e.g., CQI). In dual connectivity, two MAC entities may be configured for a wireless device: one for a MCG and one for a SCG. A MAC entity of a wireless device may handle a plurality of transport channels. A first MAC entity may handle first transport channels comprising a PCCH of a MCG, a first BCH of the MCG, one or more first DL-SCHs of the MCG, one or more first UL-SCHs of the MCG, and/or one or more first RACHs of the MCG. A second MAC entity may handle second transport channels comprising a second BCH of a SCG, one or more second DL-SCHs of the SCG, one or more second UL-SCHs of the SCG, and/or one or more second RACHs of the SCG.

If a MAC entity is configured with one or more Scells, there may be multiple DL-SCHs, multiple UL-SCHs, and/or multiple RACHs per MAC entity. There may be one DL-SCH and/or one UL-SCH on an SpCell. There may be one DL-SCH, zero or one UL-SCH, and/or zero or one RACH for an Scell. A DL-SCH may support receptions using different numerologies and/or TTI duration within a MAC entity. A UL-SCH may support transmissions using different numerologies and/or TTI duration within the MAC entity.

A MAC sublayer may support different functions. The MAC sublayer may control these functions with a control (e.g., Control **1355** and/or Control **1365**) element. Functions performed by a MAC entity may comprise one or more of: mapping between logical channels and transport channels (e.g., in uplink or downlink), multiplexing (e.g., (De-) Multiplexing **1352** and/or (De-) Multiplexing **1362**) of MAC SDUs from one or different logical channels onto transport blocks (TBs) to be delivered to the physical layer on transport channels (e.g., in uplink), demultiplexing (e.g., (De-) Multiplexing **1352** and/or (De-) Multiplexing **1362**) of MAC SDUs to one or different logical channels from transport blocks (TBs) delivered from the physical layer on transport channels (e.g., in downlink), scheduling information reporting (e.g., in uplink), error correction through HARQ in uplink and/or downlink (e.g., **1363**), and logical channel prioritization in uplink (e.g., Logical Channel Prioritization **1351** and/or Logical Channel Prioritization **1361**). A MAC entity may handle a random access process (e.g., Random Access Control **1354** and/or Random Access Control **1364**).

FIG. **14** shows an example of a RAN architecture comprising one or more base stations. A protocol stack (e.g., RRC, SDAP, PDCP, RLC, MAC, and/or PHY) may be supported at a node. A base station (e.g., gNB **120**A and/or **120**B) may comprise a base station central unit (CU) (e.g., gNB-CU **1420**A or **1420**B) and at least one base station distributed unit (DU) (e.g., gNB-DU **1430**A, **1430**B, **1430**C, and/or **1430**D), for example, if a functional split is configured. Upper protocol layers of a base station may be located in a base station CU, and lower layers of the base station may be located in the base station Dus. An F1 interface (e.g., CU-DU interface) connecting a base station CU and base station Dus may be an ideal or non-ideal backhaul. F1-C may provide a control plane connection over an F1 interface, and F1-U may provide a user plane connection over the F1 interface. An Xn interface may be configured between base station Cus.

A base station CU may comprise an RRC function, an SDAP layer, and/or a PDCP layer. Base station Dus may comprise an RLC layer, a MAC layer, and/or a PHY layer. Various functional split options between a base station CU and base station Dus may be possible, for example, by locating different combinations of upper protocol layers (e.g., RAN functions) in a base station CU and different combinations of lower protocol layers (e.g., RAN functions) in base station Dus. A functional split may support flexibility to move protocol layers between a base station CU and base station Dus, for example, depending on service requirements and/or network environments.

Functional split options may be configured per base station, per base station CU, per base station DU, per wireless device, per bearer, per slice, and/or with other granularities. In a per base station CU split, a base station CU may have a fixed split option, and base station Dus may be configured to match a split option of a base station CU. In a per base station DU split, a base station DU may be configured with a different split option, and a base station CU may provide different split options for different base station Dus. In a per wireless device split, a base station (e.g., a base station CU and at least one base station Dus) may provide different split options for different wireless devices. In a per bearer split, different split options may be utilized for different bearers. In a per slice splice, different split options may be used for different slices.

FIG. **15** shows example RRC state transitions of a wireless device. A wireless device may be in at least one RRC state among an RRC connected state (e.g., RRC Connected **1530**, RRC_Connected, etc.), an RRC idle state (e.g., RRC Idle **1510**, RRC_Idle, etc.), and/or an RRC inactive state (e.g., RRC Inactive **1520**, RRC_Inactive, etc.). In an RRC connected state, a wireless device may have at least one RRC connection with at least one base station (e.g., gNB and/or eNB), which may have a context of the wireless device (e.g., UE context). A wireless device context (e.g., UE context) may comprise at least one of an access stratum context, one or more radio link configuration parameters, bearer (e.g., data radio bearer (DRB), signaling radio bearer (SRB), logical channel, QoS flow, PDU session, and/or the like) configuration information, security information, PHY/MAC/RLC/PDCP/SDAP layer configuration information, and/or the like configuration information for a wireless device. In an RRC idle state, a wireless device may not have an RRC connection with a base station, and a context of the wireless device may not be stored in a base station. In an RRC inactive state, a wireless device may not have an RRC connection with a base station. A context of a wireless device may be stored in a base station, which may comprise an anchor base station (e.g., a last serving base station).

A wireless device may transition an RRC state (e.g., UE RRC state) between an RRC idle state and an RRC connected state in both ways (e.g., connection release **1540** or connection establishment **1550**; and/or connection reestablishment) and/or between an RRC inactive state and an RRC connected state in both ways (e.g., connection inactivation **1570** or connection resume **1580**). A wireless device may transition its RRC state from an RRC inactive state to an RRC idle state (e.g., connection release **1560**).

An anchor base station may be a base station that may keep a context of a wireless device (e.g., UE context) at least at (e.g., during) a time period that the wireless device stays in a RAN notification area (RNA) of an anchor base station, and/or at (e.g., during) a time period that the wireless device stays in an RRC inactive state. An anchor base station may comprise a base station that a wireless device in an RRC inactive state was most recently connected to in a latest RRC connected state, and/or a base station in which a wireless device most recently performed an RNA update procedure. An RNA may comprise one or more cells operated by one or more base stations. A base station may belong to one or more RNAs. A cell may belong to one or more RNAs.

A wireless device may transition, in a base station, an RRC state (e.g., UE RRC state) from an RRC connected state to an RRC inactive state. The wireless device may receive RNA information from the base station. RNA information may comprise at least one of an RNA identifier, one or more cell identifiers of one or more cells of an RNA, a base station identifier, an IP address of the base station, an AS context identifier of the wireless device, a resume identifier, and/or the like.

An anchor base station may broadcast a message (e.g., RAN paging message) to base stations of an RNA to reach to a wireless device in an RRC inactive state. The base stations receiving the message from the anchor base station may broadcast and/or multicast another message (e.g., paging message) to wireless devices in their coverage area, cell coverage area, and/or beam coverage area associated with the RNA via an air interface.

A wireless device may perform an RNA update (RNAU) procedure, for example, if the wireless device is in an RRC inactive state and moves into a new RNA. The RNAU procedure may comprise a random access procedure by the wireless device and/or a context retrieve procedure (e.g., UE context retrieve). A context retrieve procedure may comprise: receiving, by a base station from a wireless device, a random access preamble; and requesting and/or receiving (e.g., fetching), by a base station, a context of the wireless device (e.g., UE context) from an old anchor base station. The requesting and/or receiving (e.g., fetching) may comprise: sending a retrieve context request message (e.g., UE context request message) comprising a resume identifier to the old anchor base station and receiving a retrieve context response message comprising the context of the wireless device from the old anchor base station.

A wireless device in an RRC inactive state may select a cell to camp on based on at least a measurement result for one or more cells, a cell in which a wireless device may monitor an RNA paging message, and/or a core network paging message from a base station. A wireless device in an RRC inactive state may select a cell to perform a random access procedure to resume an RRC connection and/or to send (e.g., transmit) one or more packets to a base station (e.g., to a network). The wireless device may initiate a random access procedure to perform an RNA update procedure, for example, if a cell selected belongs to a different RNA from an RNA for the wireless device in an RRC inactive state. The wireless device may initiate a random access procedure to send (e.g., transmit) one or more packets to a base station of a cell that the wireless device selects, for example, if the wireless device is in an RRC inactive state and has one or more packets (e.g., in a buffer) to send (e.g., transmit) to a network. A random access procedure may be performed with two messages (e.g., 2-stage or 2-step random access) and/or four messages (e.g., 4-stage or 4-step random access) between the wireless device and the base station.

A base station receiving one or more uplink packets from a wireless device in an RRC inactive state may request and/or receive (e.g., fetch) a context of a wireless device (e.g., UE context), for example, by sending (e.g., transmitting) a retrieve context request message for the wireless device to an anchor base station of the wireless device based on at least one of an AS context identifier, an RNA identifier, a base station identifier, a resume identifier, and/or a cell identifier received from the wireless device. A base station may send (e.g., transmit) a path switch request for a wireless device to a core network entity (e.g., AMF, MME, and/or the like), for example, after or in response to requesting and/or receiving (e.g., fetching) a context. A core network entity may update a downlink tunnel endpoint identifier for one or more bearers established for the wireless device between a user plane core network entity (e.g., UPF, S-GW, and/or the like) and a RAN node (e.g., the base station), such as by changing a downlink tunnel endpoint identifier from an address of the anchor base station to an address of the base station).

A base station may communicate with a wireless device via a wireless network using one or more technologies, such as new radio technologies (e.g., NR, 5G, etc.). The one or more radio technologies may comprise at least one of: multiple technologies related to physical layer; multiple technologies related to medium access control layer; and/or multiple technologies related to radio resource control layer Enhancing the one or more radio technologies may improve performance of a wireless network. System throughput, and/or data rate of transmission, may be increased. Battery consumption of a wireless device may be reduced. Latency of data transmission between a base station and a wireless device may be improved. Network coverage of a wireless network may be improved. Transmission efficiency of a wireless network may be improved.

A wireless device may be configured with one or more uplink (UL) bandwidth parts (UL BWPs) for a cell one or more of which may be activated for the cell. A BWP to support device-to-device (D2D) or to support sidelink (SL) between wireless devices may be configured and/or activated for the cell. For example, a BWP for D2D and/or a SL may be activated at the same time (or substantially the same time) that one or more of the UL BWP are activated. If a wireless device is activated with an UL BWP and a sidelink (SL) BWP for a cell, the wireless device may determine (e.g., may be required) to switch between the UL BWP and the SL BWP. The wireless device may determine to switch between the UL BWP and the SL BWP, for example, if a first numerology of the UL BWP and a second numerology of the SL BWP are different and the wireless device does not support more than one numerology for a UL carrier at a time. Service interruptions (e.g., not receiving any data/control and/or sending/transmitting any data/control) may occur, for example, if the wireless device performs a switching operation between UL BWP and SL BWP (e.g., a service interruption may occur during the switching). A service interruption of SL operation (e.g., not receiving any SL data/control and/or sending/transmitting any SL data/control) may occur, for example, if the wireless device performs an UL BWP switching operation. A wireless device may be unable to receive SL communications during the time period that the wireless device performs BWP switching.

A reception gap may comprise a time period during which no BWP switching occurs. A base station may determine a SL reception gap for a wireless device to use SL communications. The base station may indicate/inform one or more SL wireless devices of the SL reception gap via at least one RRC, MAC, and/or DCI message. A SL wireless device may determine that there is no BWP switching (e.g., the base station will not cause and/or trigger BWP switching for a wireless device) in one or more resources configured in the SL reception gap. Based on the SL reception gap, the SL wireless device may ignore a (or any) BWP switching command/timer (e.g., bwpInactivityTimer) that may impact one or more resources configured in the SL reception gap. A second SL-sending (e.g., transmitting) wireless device from the one or more second SL-sending (e.g., transmitting) wireless devices may select one or more SL-resources from the one or more resources configured in the SL reception gap.

Wireless devices may communicate with each other directly via wireless communications, for example, device-to-device communications, vehicle-to-everything communications, vehicle-to-vehicle communications, vehicle-to-network communications, vehicle-to-roadside infrastructure communications, vehicle-to-pedestrian communications, and/or direct communications, with or without involving a base station as an intermediary. Wireless devices may exchange data without passing the data through a base station in a wireless communications scheme, for example, a direct wireless device-to-wireless device (e.g., UE-to-UE) communication scheme. Communications between wireless devices that establish a direct communication link (e.g., a sidelink) between each other may have reduced latency and/or may utilize fewer radio resources compared to communications established via a central base station.

FIGS. **16**A-**16**D show examples of wireless communications between wireless devices **1610** and **1620**. Referring to FIG. **16**A, wireless device **1610** and wireless device **1620** may perform wireless communications **1615** while located outside of range of a wireless network cell coverage provided by, for example, a base station or TRP. Referring to FIG. **16**B, wireless device **1610** and wireless device **1620** may perform wireless communications **1615** while the wireless device **1610** is located within range of a wireless network cell coverage **1640** provided by, for example, a base station or TRP **1630**, and the wireless device **1620** is located outside of range of the wireless network cell coverage **1640**. Referring to FIG. **16**C, wireless device **1610** and wireless device **1620** may perform intra-cell wireless communications **1615** while located within range of the same wireless network cell coverage **1640** provided by, for example, a base station or TRP **1630**. Referring to FIG. **16**D, wireless device **1610** and wireless device **1620** may perform inter-cell wireless communications **1615** while the wireless device **1610** is located within a first wireless network cell coverage **1640** provided by, for example, a first base station or TRP **1630**, and the wireless device **1620** is located within a second wireless network cell coverage **1660** provided by, for example, a second base station or TRP **1650**.

A wireless device (e.g., the wireless device **1610**, **1620**) may send (e.g., transmit) a wireless communications signal via a sidelink to perform one or more of discovery or communications. The wireless device **1610**, **1620** may send the wireless communications signal to discover (e.g., determine) at least one other wireless device **1620**, **1610** adjacent (e.g., closer than a base station **1630**, **1650**) to the wireless device **1610**, **1620**. The wireless device **1610**, **1620** may send (e.g., transmit) and/or receive a wireless communications signal via a physical sidelink discovery channel (PSDCH) to perform discovery of one or more other wireless devices. The wireless device **1610**, **1620** may send (e.g., transmit) the wireless communications signal to send general data (e.g., voice data, image data, video data, safety information, etc.) directly to at least one other wireless device **1620**, **1610**. A physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), a physical sidelink control channel (PSCCH), or the like may send (e.g., transmitting) and/or receive a wireless communications signal between wireless devices.

FIG. **17**A and FIG. **17**B show examples of wireless communications. FIG. **17**A shows an example of wireless communications between wireless devices having access to a base station of a wireless network. A wireless device **1710** may perform wireless communications with a wireless device **1720** by sending (e.g., transmitting) a wireless communications signal **1730** directly to the wireless device **1720**. FIG. **17**B shows an example of a resource pool **1750** for performing wireless communications. The resource pool **1750** may comprise radio resource units associated with the wireless devices **1710** and **1720** performing wireless communications. The wireless devices **1710** and **1720** may comprise a wireless terminal, access point (AP), or base station that sends (e.g., transmits) and/or receives a wireless signal for wireless communications. The wireless device **1710** may designate one or more radio resource unit(s) #(n . . . n+k−1, 0 . . . Nf−1) comprised by the resource pool

1750. The wireless device **1710** may send (e.g., transmit) the wireless communications signal **1730** based on or configured according to the designated one or more radio resource unit(s) #(n . . . n+k−1, 0 . . . Nf−1). The wireless device **1720** may receive a designation of one or more radio resource unit(s) #(n . . . n+k−1, 0 . . . Nf−1) comprised by the resource pool **1750** via which the wireless device **1710** may send (e.g., transmit) and the wireless device **1720** may receive the wireless communications signal **1730**.

The base station **1740** may send (e.g., transmit) information regarding the resource pool **1750** to the wireless device **1710**, for example, if the wireless device **1710** is located inside of a cell of network coverage provided by the base station **1740**. The wireless device **1710** may receive the information regarding the resource pool **1750** from the wireless device **1720**, for example, if the wireless device **1710** is located outside of a cell of network coverage provided by the base station **1740**. The wireless device **1710** may access internally stored pre-configured information regarding the resource pool **1750**, for example, if the wireless device **1710** is located outside of a cell of network coverage provided by any base station.

The resource pool **1750** may comprise a plurality of radio resource units #(n . . . n+k−1, 0 . . . Nf−1) indexed according to time slots (e.g., x axis) and frequency band slots (e.g., y axis). A radio resource unit may comprise one or more resource blocks (e.g., a frequency band slot, a subframe, K OFDM symbols) and a time duration. The wireless device **1710** may designate one or more radio resource unit(s) from a plurality of the radio resource units #(n . . . n+k−1, 0 . . . Nf−1) comprised by the resource pool **1750** and may send (e.g., transmit) a wireless communications signal **1730** according to the designated radio resource unit(s) for wireless communications with the wireless device **1720**. A frequency band **1760** may be divided into a plurality of Nf frequency resource blocks. Each of the plurality of radio resource units #(n . . . n+k−1, 0 . . . Nf−1) may designate one (or more) of the Nf frequency resource blocks of the frequency band **1760**. A time period **1770** may be divided into a plurality of k time resource blocks (e.g., time slot). Each of the plurality of radio resource units #(n . . . n+k−1, 0 . . . Nf−1) may designate one (or more) of the Nf frequency resource blocks of the frequency band **1760**. The resource pool **1750** may be temporally repeated with a period of k time resource blocks. The resource pool **1750** may comprise a frequency band within a bandwidth part (BWP) for wireless communications or sidelink communications (e.g., a SL BWP). The given radio resource units #(n . . . n+k−1, 0 . . . Nf−1) may periodically and/or repeatedly appear over time. An index of a radio resource unit to which a logical resource unit is mapped may change with a predetermined pattern according to a value of time to generate a diversity gain in the time domain and/or the frequency domain. The resource pool **1750** may correspond to a set of radio resource units that the wireless devices **1710**, **1720** may utilize for sending (e.g., transmitting) and/or receiving wireless communications signals **1730**.

The resource pool **1750** may be classified according to contents of a wireless communications signal **1730** transmitted via the resource pool **1750**. A plurality of wireless communications signals **1730** may be classified according to information content to be sent via the respective wireless communications signals **1730**, and a separate resource pool **1750** may be allocated for each of the classifications of the wireless communications signals **1730**. The resource pool **1750** may be allocated based on information content of the corresponding wireless communications signal **1730**. The information contents of the wireless communications signal **1730** may include a control channel, a data channel, and/or a discovery channel. The control channel may correspond to a wireless communications signal **1730** that may comprise information indicating/specifying a radio resource position of a data channel, information indicating/specifying an MCS for modulating and demodulating a data channel, information indicating/specifying a MIMO transmission scheme, information specifying packet priority, information indicating/specifying target coverage, information specifying QoS requirements, or the like. The control channel may be multiplexed with and sent (e.g., transmitted) on a same radio resource unit as a data channel A control and data channel resource pool may correspond to a resource pool **1750** via which control information and data information are multiplexed and sent (e.g., transmitted). The control channel may comprise a physical sidelink control channel (PSCCH). The data channel may comprise a physical sidelink shared channel (PSSCH) corresponding to a resource pool **1750** via which the wireless device **1710** sends (e.g., transmits) user data to the wireless device **1720**. A data channel excluding control information may be sent (e.g., transmitted) in a resource pool **1750** dedicated to the data channel, for example, if control information and data information are multiplexed in a same radio resource unit and sent (e.g., transmitted). The wireless devices **1710** and **1720** may send (e.g., transmit) control information in a designated resource unit of a control resource pool and data information in a data resource pool via the same resource elements (Res). The wireless device **1710** may send (e.g., transmit) one or more messages via a discovery channel corresponding to a resource pool **1750** dedicated to the discovery channel to facilitate neighboring wireless devices, for example, the wireless device **1720**, to discover the wireless device **1710** sending (e.g., transmitting) information such as identification (ID) information pertaining to the wireless device **1710** and/or the like.

The resource pool **1750** may be classified according to QoS level and/or associated service. The base station **1740** may designate a priority level for each resource pool **1750**. The resource pool **1750** may be configured differently for different associated services. A specific resource pool **1750** may be configured for use by only specific unicast or groupcast wireless devices. Different resource pools **1750** may be designated for different wireless communications signals **1730**, for example, based on one or more transmission/reception attributes of the wireless communications signals **1730**. Different resource pools **1750** may be designated for different wireless communications signals **1730**, for example, regardless of whether or not information contents of the wireless communications signals **1730** are identical to each other.

Different instances of a same data channel or a same discovery signal/message may be associated with differently classified resource pools **1750**. The resource pool **1750** may be classified according to contents of a data channel or a discovery signal/message based on a transmission timing determination scheme of a wireless communications signal **1730** (e.g., whether the wireless communications signal **1730** is sent (e.g., transmitted) at a time based on a time of receiving a synchronization reference signal, for example, at the time of receiving the synchronization reference signal or a different time based on the addition of a timing advance value). The resource pool **1750** may be classified according to contents of a data channel or a discovery signal/message based on a resource allocation scheme (e.g., whether a base station designates a transmission resource of an individual wireless communications signal **1730** or a wireless device designates the transmission resource of the individual wireless communications signal **1730** from a resource pool **1750**). The resource pool **1750** may be classified according to contents of a data channel or a discovery signal/message based on a signal format of a wireless communications signal **1730** (e.g., a number of symbols occupied by a wireless communications signal **1730** in a subframe, or a number of subframes used for sending (e.g., transmitting) a wireless communications signal **1730**). The resource pool **1750** may be classified according to contents of a data channel or a discovery signal/message based on signal strength from a base station (e.g., the base station **1740**), transmit power level of a wireless device (e.g., wireless device **1710**) sending (e.g., transmitting) the wireless communications signal **1730**, and/or the like.

Transmission resource designation methods may be categorized as different modes and/or types. A base station (e.g., base station **1740**) may deignate (e.g., directly designate) a transmission resource to be used by a wireless device (e.g., the wireless device **1710**) for sending (e.g., transmitting) a wireless communications signal using a mode 1. The base station (e.g., eNB, gNB, etc.) may send (e.g., transmit) DCI to schedule a transmission of a wireless communications signal **1730** according to mode 1. A wireless device (e.g., wireless device **1710**) may directly designate a transmission resource from a pre-configured transmission resource region or resource pool **1750** or from a transmission resource region or resource pool **1750** designated by a base station (e.g., base station **1740**) using a mode 2. A base station (e.g., base station **1740**) may designate (e.g., directly designate) a transmission resource to be used by a wireless device (e.g., the wireless device **1710**) for performing a Type 2 discovery. A wireless device (e.g., wireless device **1710**) may designate (e.g., directly designate) a transmission resource from a pre-configured transmission resource region or resource pool **1750** or from a transmission resource region or resource pool **1750** designated by a base station (e.g., base station **1740**) for performing a Type 1 discovery.

The wireless device **1710** and the wireless device **1720** may perform time synchronization and/or frequency synchronization with one another, for example, to perform wireless communications with one another. The base station **1740** may synchronize the time and frequency references of the wireless devices **1710** and **1720** (e.g., by PSSs/SSSs of a cell provided by the base station **1740**, other reference signals (e.g., CSI-RSs), and/or the like transmitted by the base station **1740**), if the wireless devices **1710** and **1720** both are located within the network coverage of the cell. The wireless devices **1710** and **1720** may maintain time/frequency synchronization in a level that the wireless devices **1710** and **1720** are capable of directly sending (e.g., transmitting) and receiving a signal. The wireless device **1710** may send (e.g., transmit) a synchronization signal (e.g., a sidelink synchronization signal (SLSS)) and the wireless device **1720** may receive and synchronize with the synchronization signal. The SLSS may comprise a sidelink primary synchronization signal (S-PSS) and/or a sidelink secondary synchronization signal (S-SSS). The wireless device **1710** may send (e.g., transmit) the SLSS with a physical sidelink broadcast channel (PSBCH) to convey some basic or initial system information. The wireless devices **1710**, **1720** may synchronize or derive a timing of transmission time intervals (e.g., frames, subframes, slots, and/or the like) using global navigation satellite system (GNSS) timing. S-PSS, S-SSS and PSBCH may be structured in a block format (e.g., sidelink synchronization signal block (S-SSB)) and may support periodic transmission. The S-SSB may use a same numerology (e.g., SCS and CP length) as a sidelink data channel and a sidelink control channel in a carrier. The S-SSB's transmission bandwidth may be within the pre-configured sidelink BWP. The S-SSB's frequency location may be pre-configured. The wireless device (e.g., the wireless device **1710**) may forego performing hypothesis detection in frequency to find S-SSB in a carrier, if the S-SSB's frequency location is pre-configured. Sidelink synchronization sources may include GNSS, gNB, eNB, and/or NR UE. Each sidelink synchronization source may be associated with a synchronization priority level A priority order of the sidelink synchronization sources and/or synchronization priority levels may be pre-configured.

Each of a plurality of neighboring wireless devices **1710**, **1720** may designate one or more subchannels of a resource pool **1750** for sending (e.g., transmitting) a wireless communications signal **1730**. A frequency bandwidth of the resource pool **1750** may be divided into multiple subchannels. A wireless device **1710**, **1720** may designate a subchannel, for example, based on received energy measurements and/or control channel decoding. A wireless device **1710**, **1720** may determine a subchannel that another wireless device **1710**, **1720** is designating for use, for example, based on control channel decoding and/or an energy measurement for each subchannel. In-band emissions (IBEs) may effectively impose a limit on system performance. An in-band emission may comprise interference caused by one transmitter transmitting on one subchannel and imposed on another transmitter transmitting to a receiver on another subchannel.

FIG. **18** shows an example of an in-band emissions (IBE) model. Subchannels nearby to a desired transmitted signal **1810**, as well as other subchannels (e.g., I/Q image subchannels **1820**) may experience more interference, as shown in FIG. **18**. General in-band emissions **1830** tend to be stronger close in frequency to the desired transmitted signal **1810**. Carrier leakage **1840** tends to be generated around a direct current or direct conversion (DC) subcarrier. The I/Q image subchannels **1820** may be located in symmetrical subchannels of the desired transmitted signal around the DC subcarrier.

A wireless device **1710** radiating power in association with performing wireless communications within a cell of a wireless network provided by a base station **1740** may cause serious interference to the cellular communications of the cell. If the wireless device **1710** performing wireless communications uses only some frequency resources in a particular slot or subframe, the in-band emission of the power radiated by the wireless device **1710** may cause serious interference to the frequency resources used by the cellular communications network. The wireless device **1710** performing wireless communications may perform cellular pathloss-based power control to prevent excess interference that causes these problems. The base station **1740** may configure parameters used for power control (e.g., P0 or alpha).

A wireless device **1710** that sends (e.g., transmits) a wireless communications signal **1730** may correspond to a half-duplex wireless device, which may not be capable of receiving a signal at a same time of sending a signal (e.g., performing transmission). The wireless device **1710** may fail to receive a signal sent (e.g., transmitted) by another wireless device **1720** due to the half-duplex problem. Different wireless devices **1710**, **1720** performing wireless communications may send (e.g., transmit) signals via one or more different time resources to mitigate the half-duplex problem.

Direct wireless communications between wireless devices in proximity to each other (e.g., closer to each other than the wireless devices are to a base station or sufficiently close to each other for the wireless devices to establish a reliable communication link with each other) may have various advantages. For example, the wireless devices participating in direct wireless communications with each other may have a high data transfer rate with low latency for data communications. Wireless devices performing wireless communications between each other in a wireless network cell may reduce network traffic concentration on a base station of the cell, for example, by distributing network traffic among direct connections between wireless devices in the cell. A wireless device, in a cell of a wireless network, performing wireless communications with another wireless device outside the cell, may perform a communications relay role and thereby effectively extend the communications reach and/or cell coverage of a base station that provides the cell's network communications.

FIG. **19** shows an example of wireless communications between various vehicles and wireless devices. At least one automotive vehicle **1910**, **1920** may apply the wireless communications methods described herein for sending and/or receiving communications signals and messages to and/or from an automotive vehicle (e.g., vehicle-to-everything (V2X) communications). V2X communications may include wireless communications between a vehicle and another vehicle, for example, vehicle-to-vehicle (V2V) wireless communications. V2X communications may include wireless communications between a vehicle and a portable wireless device **1930** carried by an individual (e.g., handheld wireless terminal carried by a pedestrian, cyclist, driver, or passenger), for example, vehicle-to-pedestrian (V2P) wireless communications. V2X communications may include wireless communications between a vehicle and an infrastructure/network and/or roadside unit (RSU)/network **1940** (e.g., traffic light and/or signal), for example, vehicle-to-infrastructure/network (V2I/N) wireless communications. An RSU **1940** may include a transportation infrastructure entity implemented in a base station or a stationary wireless device proximate a road or highway. The RSU may comprise, for example, an entity sending (e.g., transmitting) speed notifications to vehicles and/or wireless devices in the vicinity of a road or highway. A vehicle, an RSU, a stationary wireless device, and/or a portable wireless device may comprise a transceiver configured to perform V2X communications.

A vehicle **1910**, **1920**, a portable wireless device **1930**, and/or an RSU **1940** may perform V2X communications to indicate warnings for various safety-related events and the like. The vehicle **1910** may perform V2X communications to send information regarding an event occurring on the vehicle **1910** or road via which the vehicle **1910** is traveling to another vehicle **1920**, the RSU **1940**, and/or a pedestrian's portable wireless device **1930**. The information regarding the event may comprise a warning of a traffic accident on the road, a change of a road situation, and/or occurrence of an accident involving the vehicle **1910**. The vehicle **1910** may perform V2X communications to send information regarding the event to a pedestrian adjacent to or crossing a road via the pedestrian's portable wireless device **1930**, for example, as the vehicle **1910** approaches the pedestrian.

At least one vehicle **1910**, **1920**, portable wireless device **1930**, and/or RSU **1940** may be configured for performing V2X communications, for example, to prevent and/or reduce vehicle collisions and/or improve communications quality of service in geographic locations having a high density of wireless devices **1930**, for example, in city downtowns. At least one vehicle **1910**, **1920**, portable wireless device **1930**, and/or RSU **1940** may be configured for performing wireless congestion control, for example, in conjunction with V2X communications, to mitigate collisions by adjusting one or more communications parameters to control a congestion level on the wireless channel(s) used by the at least one vehicle **1910**, **1920** and improve reliability of V2X communications.

In some types of wireless communications, a wireless device may measure a channel busy ratio (CBR) and/or a channel occupancy ratio (CR). The wireless device may measure the CBR and/or CR, for example, to determine (e.g., characterize) the channel state, and/or allow/facilitate the wireless device to determine and/or take corrective actions. The CBR may be determined based on a portion (or quantity) of subchannels in a radio resource pool having measured RSSIs exceeding a threshold (e.g., a configured threshold, or a pre-configured threshold such as may be pre-configured by a base station). The total frequency resources of the radio resource pool may be divided into a quantity (e.g., a given number) of subchannels. The CBR may be sensed over, for example, the last 100 subframes (e.g., with subframes determined according to LTE or other standard or access technology), or any other duration or period (e.g., slots determined based on NR or any other access technology). The CBR may determine an estimate of a state of the channel. The CR may be determined at subframe n as a sum of the total number/quantity of subchannels used for sidelink transmissions in subframes ([n−a, n−1] subchannels) and granted in subframes ([n, n+b] subchannels), divided by a total number of subchannels ([n−a, n+b] subchannels). Values for the variables a and b may be determined by the wireless device based on the conditions $a+b+1=1000$, $a \geq 500$. The CR may provide an indication of the channel utilization by the transmitter of the wireless device. A wireless device's CR limit, for each interval of CBR values, may represent a maximum footprint for the transmitter of the wireless device. A base station may establish the CR limit based on a CBR range and packet priority. The base station may establish a low CR limit, for example, if a high CBR is observed. The base station may establish a low CR limit, for example, based on a low packet priority level. The base station may map its CBR value to the correct interval to determine the corresponding CR limit value, for example, if transmitting a data packet. The wireless device may decrease its CR below the CR limit, for example, if the wireless device's CR is higher/greater than the CR limit. Various methods may be practiced to reduce the CR, for example. A base station may disable packet retransmission, for example, via a drop packet retransmission procedure. A base station may disable packet transmission and retransmission, for example, via a drop packet transmission procedure. A wireless device may reduce CR by augmenting the utilized MCS index, for example, via a procedure for adapting the MCS. The wireless device adapting the MCS may reduce the quantity of subchannels used for transmission. The wireless device increasing the MCS may reduce robustness of the message that the wireless device sends, and may consequently reduce a range of the message. A wireless device may reduce transmission power, for example, via a procedure for adapting the transmission power. The wireless device reducing transmission power may reduce overall CBR in the area, and may increase the value of the CR limit.

Some types of wireless communications may comprise mode 1 wireless devices and/or mode 2 wireless devices (and/or any other wireless devices). For mode 1 wireless devices, a base station may schedule SL resources to be used for SL communication (e.g., transmission). For mode 2 wireless devices, instead of the base station determining SL resources, the mode 2 wireless device may determine SL resources for SL communication (e.g., transmission). For example, instead of receiving updated resource scheduling information from a base station and using it for SL communication, the mode 2 wireless device may determine SL resources for SL communication based on previously configured SL communication types. A mode 2 wireless device may be unaware of if and/or when a mode 1 device or other device is unable to send and/or receive information (e.g., because the mode 2 device may have not received scheduling information from the base station). For example, the mode 2 device may not know and/or be able to determine if a mode 1 device is switching a BWP. Information sent (e.g., via SL) may fail to reach its intended destination, for example, if it is sent to a wireless device during a time at which the mode 1 wireless device is unable to receive information. If the information is not received, it may need to be sent again, causing additional power consumption, interference with other wireless signals, increasing latency, and/or decreasing reliability of communication. Similar problems may arise for mode 1 wireless devices, mode 2 wireless devices, and/or any other wireless device.

In wireless communications described herein, wireless devices (e.g., a mode 1 wireless device, a mode 2 wireless device, and/or any other wireless device), and/or a base station may determine one or more reception gaps (e.g., time periods) for sending information (e.g., no BWP switching and/or uplink/downlink scheduling will occur during the reception gap; or BWP switching and/or uplink/downlink scheduling has a reduced likelihood of occurring during the reception gap). Additionally or alternatively, the wireless devices and/or the base station may determine reception gaps during which information should not be sent (e.g., BWP switching and/or uplink/downlink scheduling may occur during the reception gap). The wireless devices and/or base station may send information to each other indicating the determined reception gaps (e.g., when the reception gaps will occur or when they are likely to occur). The wireless devices may communicate via SL based on the determined time periods (e.g., to allow SL communications to reach the intended recipient the first time they are sent). Coordinating SL communication may reduce power consumption of wireless devices, for example, by decreasing the number/quantity of times information needs to be sent. Coordinating SL communications may reduce interference with wireless signals and/or may reduce latency. Coordinating SL communication may increase reliability of wireless communications. Coordination may improve the ability for a wireless device to receive a communication the first time it is sent and/or reduce the likelihood and/or quantity of retransmissions. For example, a vehicle may receive safety information such as speed, location, and direction of another vehicle more quickly (e.g., the first time the information is sent and/or with fewer retransmissions) for wireless devices such as vehicle-to-anything (V2X) wireless devices. Wireless communications between any wireless devices (e.g., via a SL) for a variety of applications may be improved, as described further herein.

If a wireless device switches from one BWP to another BWP, there may be a switching period during which the wireless device may not be expected to send (e.g., transmit) and/or receive information (e.g., at least one message, transport block, data, control information, etc.). For example, the wireless device may be unable to send and/or receive information during switching of its active DL and/or UL from a BWP to another BWP.

For DCI-based BWP switching, after the wireless device (e.g., a mode 1 wireless device or a mode 2 wireless device) receives a BWP switching request at DL slot n via a serving cell, the wireless device may be able to receive PDSCH transmission (e.g., for DL active BWP switching). Additionally or alternatively, the wireless device may be able to send (e.g., transmit) PUSCH transmission (e.g., for UL active BWP switch) on or using the new BWP via the serving cell on which BWP switching (e.g., for the first DL or UL slot) occurs (e.g., after or immediately after the beginning of a DL slot and/or any associated delay (e.g., DLslot n+TBWPswitchDelay)). The wireless device may disregard one or more requirements (e.g., described herein), for example, if performing a DCI-based BWP switch between the BWPs in disjoint channel bandwidths and/or in partially overlapping channel bandwidths. For a timer-based BWP switching, the wireless device may start BWP switching at DL slot n, where n may be the beginning of a DL subframe (e.g., FR1) or DL half-subframe (e.g., FR2) after (e.g., immediately after) a BWP-inactivity timer (e.g., bwp-InactivityTimer) expires on a serving cell. The wireless device may be able to receive a PDSCH transmission (e.g., for DL active BWP switch) and/or send (e.g., transmit) a PUSCH transmission (e.g., for UL active BWP switching) on or using the new BWP via the serving cell. The serving cell may be the cell via which BWP switching on the first DL and/or UL slot occurs, for example, after (e.g., immediately/right) after the beginning of a DL slot and/or any associated delay (e.g., DL slot n+TBWPswitchDelay).

The wireless device may not be required to send (e.g., transmit) UL signals and/or receive DL signals, for example, during a time duration (e.g., during TBWPswitchDelay) via the cell on which a DCI-based BWP switching and/or timer-based BWP switching occurs. The wireless device may finish a BWP switching within the time duration (e.g., TBWPswitchDelay), for example, based on wireless device capability.

FIGS. **20**A-**20**B show example BWP configurations. The BWP configurations may be over time **2002** and/or frequency **2001**. A SL BWP **2015** (in FIG. **20**A) and/or a resource pool for sidelink operation **2030** (in FIG. **20**B) may be configured to support wireless communications with devices outside the coverage of a cell (e.g., between two devices that are outside of the coverage) and/or within partial coverage of a cell (e.g., between one device that is outside the coverage and one device that is within the coverage of the cell) and/or inside the coverage of a cell (e.g., between two devices that inside of the coverage). The resource pool for sidelink operation **2030** may be a resource pool that is selected by a mode 2 wireless device. A wireless device outside the coverage (out of coverage wireless device) may be unable to communicate, via SL, with an in-coverage wireless device, for example, if the in-coverage wireless device switches the SL BWP **2015** and/or resources used in resource pool **2030**. For example, the out-of-coverage wireless device may not know and/or may not be able to determine the BWP switching information of the in-coverage wireless device (e.g., the BWP that the in-coverage wireless device switched to for SL communication) and/or may be unable to determine the correct BWP for SL communication. To avoid this problem, SL BWP **2015** and/or resource pool **2030** may remain unchanged and/or devices may avoid signaling activate/deactivate messages via a SL and/or via a DL. Switching Uu (e.g., downlink or uplink) BWP may cause an interruption of SL communication. For example, a mode 1 wireless device (e.g., an in-coverage wireless device as described herein, and/or a mode 1 wireless device **2103** as described in connection with FIGS. **21-24**) may receive information from a base station that may cause the mode 1 wireless device (or other wireless device) to switch from Uu BWP **2005** to Uu BWP **2010**. A Uu BWP switching delay and/or reception gap **2020**, and/or other interruption **2035** may be the time period during which the mode 1 wireless device (or other wireless device) switches from Uu BWP **2005** to Uu BWP **2010**. The mode 1 wireless device may be unable to send and/or receive information, for example, during the Uu switching delay **2020** (and/or other interruption **2035**). The mode 1 wireless device may be unable to send or receive information, for example, during a Uu BWP switching delay and/or reception gap **2025** (e.g., the time during which the mode 1 device switches back from the Uu BWP **2010** to the Uu BWP **2005**) or for example, during the interruption **2045**. The mode 1 device may not receive the communication, for example, if an out-of-coverage device or mode 2 wireless device (e.g., the mode 2 wireless device **2102** discussed below in connection with FIGS. **21-27**) sends a SL communication to the mode 1 wireless device during the delay **2020** or delay **2025**. As a result, the mode 2 wireless device may need to resend the communication.

A mode 1 wireless device's communication (e.g., transmission) resources may be scheduled by a base station (e.g., gNB, eNB, or any other base station) so that BWP switching does not occur, for example, when a mode 2 wireless device communicates, via SL, with the mode 1 wireless device. For mode 1 wireless devices, communication (e.g., transmission) resources may be controlled by a base station. A lack of assistance/control for reception resources for mode 1 wireless devices may cause problems with SL communication and/or other problems. To solve these problems, a base station may help the resource selection of the mode 2 wireless device. Additionally or alternatively, a base station may assist the reception operation of the mode 1 wireless device.

To mitigate the SL operation interruption, a base station (e.g., gNB, eNB, or any other base station) may notify mode 2 wireless devices (or other wireless devices) of a reception gap (e.g., SL reception gap **2040** and/or SL reception gap **2050**). The reception gap may be the time period during which BWP or other resource switching may occur (e.g., may potentially occur) (e.g., SL communication should not occur during this period). For example, a resource may be switched from resource **2055***a* to resource **2055***b* in SL reception gap **2040** (and/or from resource **2055***c* to resource **2055***d* in SL reception gap **2050**). Alternatively, the reception gap may be a time period during which BWP or other resource switching may not and/or does not occur (e.g., SL communication should be made during this period). The mode 1 wireless device's (or other wireless device's) SL reception gap information may be sent (e.g., signaled) via an RRC message and/or via a SIB message to mode 2 wireless devices. The SL reception gap information may indicate a specific time interval for allowing reception of a wireless communication (e.g., SL, D2D, etc.) signal. The SL reception gap information may comprise, for example, an offset, time interval (e.g., a number of symbols, slots, subframes, and/or frames), bitmap, and/or periodicity. The offset may comprise a symbol, slot, subframe, and/or frame offset. For example, the offset may be with respect to system frame number 0 and/or a slot receiving DCI, MAC CE, and/or RRC message conveying, for example, the SL reception gap information. A bitmap may comprise a symbol level, slot level, subframe level, and/or frame level bitmap. Each bit in a bitmap may, for example, indicate a symbol, slot, subframe, and/or frame. The gap information may assist and/or coordinate SL (e.g., it may indicate reception for mode 1 wireless devices and/or transmission for mode 2 wireless devices or other wireless devices) communication (e.g., operation). A mode 2 wireless device (or other wireless device) may determine its communication (e.g., transmission) resource(s) for sending information to a mode 1 wireless device (or other wireless device), for example, based on the gap information. A wireless device may select one resource pool for communication (e.g., transmission), for example, if multiple resource pools are allowed for SL communication. The wireless device may notify a mode 2 wireless device (or other wireless device) of the selection. The mode 2 wireless device (or other wireless device) may select communication (e.g., transmission) resources (e.g., resources **2055***a-d*) that are overlapped (e.g., that are both in the selected resource pool and in the SL reception gap information).

FIG. **21** shows an example method for coordinating BWP switching. A base station **2101** may coordinate communications between a mode 2 wireless device **2102** (or other wireless device) and a mode 1 wireless device **2103** (or other wireless device) by sending information to the mode 2 wireless device **2102**. Although one or more steps of the example method of FIG. **21** are described for convenience as being performed by the base station **2101**, the mode 2 wireless device **2102**, and/or the mode 1 wireless device **2103**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any device described in connection with FIGS. **1-20**. One or more steps of the example method of FIG. **21** may be rearranged, modified, repeated, and/or omitted.

At step **2105**, the base station **2105** may send SL reception gap information to the mode 2 wireless device **2102** (or other wireless device). For example, the base station **2105** may send the information via a radio resource control (RRC) and/or via a system information block (SIB) message. The reception gap information may allow the mode 2 wireless device **2102** to configure SL communications, for example, based on the reception gap of the mode 1 wireless device **2103**. Although only one mode 2 wireless device is shown in FIG. **21**, the base station **2101** may send the reception gap information to any number of mode 2 wireless devices (or other wireless devices). Each wireless device that receives the reception gap information may use it to select communication resources as described below in step **2107** (e.g., each mode 2 wireless device may use the same resources for SL communication). At step **2107**, the mode 2 wireless device **2102** (or other wireless device) may determine the resources of the signal to be sent (e.g., transmitted) to the mode 1 wireless device **2103** (or other wireless device), for example, based on the reception gap information received in step **2105**. At step **2109**, the mode 2 wireless device **2102** may send a SL signal to the mode 1 wireless device **2103** (e.g., using the resources determined in step **2107**).

The mode 1 wireless device **2103** (or other wireless device) may select one or more reception gaps, for example, if multiple reception gaps are configured by the base station. The Mode 1 wireless device **2103** may determine which reception gap is selected and may send the selected gap information to the mode 2 wireless device **2102** (or other wireless device). For example, the selected gap information may be sent via a SL physical layer (e.g. PSCCH) and/or via a higher layer control signal (e.g. SL MAC or SL RRC). The mode 1 wireless device **2103** may send the reception gap information selected by the wireless device **2102** in step **2107** to the base station (e.g., using the physical layer or higher layer signal). The mode 2 wireless device **2102** may send a request to the mode 1 wireless device **2103**. The request may indicate a gap of a specific pattern (e.g., SL communication pattern) followed by the mode 2 wireless device **2102**. For example, the pattern may indicate whether and/or when to exchange physical layer and/or upper layer control signals in the process of exchanging information with each other. The mode 1 wireless device **2103** may send the pattern back to the base station **2101**. Within a SL reception gap, the mode 1 wireless device **2103** may expect to not be interrupted by BWP switching, UL transmission, or any other cellular operation. The mode 1 wireless device **2103** may be able to receive SL signals without interruption during the reception gap.

FIG. **22** shows an example method for coordinating BWP switching. The base station **2101** may coordinate communications between a mode 2 wireless device **2102** (or any other wireless device) and a mode 1 wireless device **2103** (or any other wireless device), for example, by sending information to both the mode 2 wireless device **2102** and the mode 1 wireless device **2103**. The mode 1 wireless device may determine communication resources (e.g., for SL communication), for example, based on the information from the base station, and/or may notify the mode 2 wireless device of its determination. The mode 2 wireless device may determine a communication resource (e.g., for SL communication), for example, based on the information from the base station and the determination made by the mode 1 wireless device. Although one or more steps of the example method of FIG. **22** are described for convenience as being performed by the base station **2101**, the mode 2 wireless device **2102**, and/or the mode 1 wireless device **2103**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-20**. One or more steps of the example method of FIG. **22** may be rearranged, modified, repeated, and/or omitted.

At step **2202**, information indicating multiple reception gaps may be sent to the mode 2 wireless device **2102** and/or the mode 1 wireless device **2103**. The reception gap information may be sent via the base station **2101**. For example, the base station **2101** may configure a plurality of SL reception gaps and/or send them to the mode 2 wireless device **2102** and the mode 1 wireless device **2103**. At step **2204**, there may be a SL connection establishment between the mode 2 wireless device **2102** and the mode 1 wireless device **2103**. For example, there may be an exchange of traffic information between the devices. The mode 1 wireless device **2103** may select one or more of the reception gaps. At step **2206**, the assisted information for reception (e.g., the one or more reception gaps selected in step **2204**) may be sent to the base station **2101**. For example, the mode 1 wireless device may send its selection information (e.g., one or more reception gaps of the plurality of SL reception gaps it received in step **2202**) to the base station **2101**. At step **2208**, the selected gap information may be sent (e.g., transmitted) to the mode 2 wireless device **2102**. For example, the mode 1 wireless device **2103** may send the reception gap information selected in step **2204** to the device **2102** via a SL control (e.g., using PSCCH, SL MAC, and/or SL RRC).

At step **2210**, the mode 2 wireless device **2102** may determine one or more transmission resources based on the gap information (e.g., the information received in step **2208**). For example, the mode 2 wireless device **2102** may select one or more reception gaps that correspond to the gap information received in step **2208**, for example, if multiple reception gaps are configured by the base station **2101**. The mode 2 wireless device **2102** may send (e.g., transmit) its selected gap information to the mode 1 wireless device **2103** via a physical layer (e.g. PSCCH) and/or via a higher layer control signal (e.g. SL MAC or SL RRC). The mode 1 wireless device may report the gap information selected by the mode 2 wireless device to the base station **2101** (e.g., via RRC or MAC signaling). The base station **2101** may avoid triggering BWP switching within the selected gap. Additionally or alternatively, the mode 1 wireless device may ignore BWP switching commands received during the selected gap. For example, the wireless device may postpone an inactivity timer expiry (e.g., inactivityTimer expiry) (e.g., if BWP switching occurs due to the inactivity timer), ignore BWP switching DCI, and/or not receive (e.g., ignore) information via Uu.

FIG. **23** shows an example method for coordinating BWP switching. The base station **2101** may coordinate communications between a mode 2 wireless device **2102** (or any other wireless device) and a mode 1 wireless device **2103** (or any other wireless device), for example, by sending information to both the mode 2 wireless device **2102** and the mode 1 wireless device **2103**. The mode 2 wireless device **2102** may determine communication resources, for example, based on the information received from the base station **2101** and may notify the mode 1 wireless device **2103** of the determination. The mode 1 wireless device **2103** may send an indication of the determined resources to the base station **2101** (e.g., to ensure that the base station does not interfere with the mode 2 wireless device's **2102** determination of communication resources). Although one or more steps of the example method of FIG. **23** are described for convenience as being performed by the base station **2101**, the mode 2 wireless device **2102**, and/or the mode 1 wireless device **2103**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-20**. One or more steps of the example method of FIG. **23** may be rearranged, modified, repeated, and/or omitted.

At step **2302**, the base station **2101** may send a plurality of SL reception gaps to SL wireless devices (e.g., the mode 2 wireless device **2102** and/or the mode 1 wireless device **2103**). The reception gaps may be sent via RRC and/or via SIB. At step **2304**, the mode 2 wireless device **2102** may select one or more of the plurality of SL reception gaps (e.g., received in step **2302**) for sending (e.g., transmission) to the mode 1 wireless device **2103**. The mode 2 wireless device **2102** may send the selection of gaps to the mode 1 wireless device **2103** (e.g., via a PSCCH and/or via a higher layer signaling). At step **2306**, the mode 1 wireless device may send the selected SL gap information (e.g., received in step **2304**) to the base station. For example, the selected SL gap information may be sent via a physical layer and/or via a higher layer signaling. At step **2308**, the mode 2 wireless device may determine the SL signal transmission resource using the information (e.g., based on the selected SL reception gap information determined in step **2304**).

The direct current or direct conversion (DC) subcarrier of Uu BWP may be different from the BWP of SL. DC subcarriers may receive higher interference than other subcarriers. The wireless device may send (e.g., transmit) a signal to a base station (e.g., gNB, eNB, and/or any other base station) to indicate the DC subcarrier of the UL BWP. By indicating the DC subcarrier, the base station may puncture the information received on the subcarrier in a decoding process, which may improve the decoding performance.

FIG. **24** shows an example method for coordinating BWP switching. The mode 1 wireless device **2103** (or any other wireless device) may communicate with the mode 2 wireless device **2102** (or any other wireless device) to coordinate BWP switching. The mode 1 wireless device **2103** may notify the base station **2101**. Although one or more steps of the example method of FIG. **24** are described for convenience as being performed by the base station **2101**, the mode 2 wireless device **2102**, and/or the mode 1 wireless device **2103**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-20**. One or more steps of the example method of FIG. **24** may be rearranged, modified, repeated, and/or omitted.

At step **2402**, the mode 1 wireless device **2103** may send information for assisting SL Rx communications to the mode 2 wireless device **2102**. For example, the information may be sent via SL signal (e.g. PSCCH, MAC or RRC). At step **2404**, the mode 1 wireless device **2103** may send the information to the base station **2101**. For example, the information may be sent to the base station **2101** via physical layer signaling (e.g., PUSCH and/or PUCCH) and/or via higher layer signaling (e.g. MAC or RRC). At step **2406**, the mode 2 wireless device **2102** may determine its transmission resource, for example, based on the information received from the mode 1 wireless device in step **2402**. At step **2408**, the mode 2 wireless device **2102** may send a SL signal communication (e.g., transmission) to the mode 1 wireless device **2103** (e.g., using the communication resource determined in step **2406**).

FIGS. **25**A-**25**C show example methods for coordinating DC subcarriers between devices. Although one or more steps of the example methods of FIGS. **25**A-**25**C are described for convenience as being performed by the base station **2101** and/or the wireless device **2503**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-24**. One or more steps of the example methods of FIGS. **25**A-**25**C may be rearranged, modified, repeated, and/or omitted.

A wireless device may frequently switch BWP, for example, if the UL BWP is configured separately from the SL BWP, and/or if the DC subcarrier of the UL BWP is different from the DC subcarrier of the SL BWP. Frequently switching BWP may cause unnecessary switching delays and may interrupt SL operation. The DC subcarrier of the UL BWP may be changed to match the DC subcarrier of the SL, for example, for a wireless device performing SL operation. The SL DC subcarrier may be fixed (e.g., may remain unchanged) to avoid and/or reduce the likelihood of degrading the SL reception performance of wireless devices in an RRC idle state. A wireless device may determine a DC subcarrier to use for SL communications. The wireless device may notify the base station **2101** of the determination. Different wireless devices within the coverage area of the base station **2101** may use different DC subcarriers (e.g., because each wireless device may determine its DC subcarrier independently).

At step **2505** of FIG. **25**A, the wireless device **2503** may send its DC subcarrier information for SL BWP to the base station (e.g., via RRC message/signaling). The base station **2101** may use the SL DC subcarrier for UL reception, for example, instead of the DC subcarrier of the UL BWP. The base station **2101** may use the SL DC subcarrier for UL reception, for example, if the wireless device performs the SL operation and/or if the SL BWP is activated. At step **2520** of FIG. **25**B, DC subcarrier information may be received. For example, a base station may receive, from a wireless device (e.g., via RRC message), DC subcarrier information for SL communication. At step **2530** of FIG. **25**B, information received in the DC subcarrier may be punctured or skipped. The base station **2101** may puncture or skip information received on the DC subcarrier (e.g., the DC subcarrier indicated by the DC subcarrier information in step **2520**), for example, if a UL signal is received from a wireless device (e.g., the wireless device in step **2520**).

At step **2510** of FIG. **25**A, the wireless device **2503** may send (e.g., transmit) a UL signal using the SL DC subcarrier corresponding to the subcarrier information sent in step **2505**. The UL signal may be sent using the SL DC subcarrier, for example, if the wireless device **2503** is not performing an SL operation (e.g., it may send/transmit an UL signal using the DC subcarrier set in the UL BWP). The DC subcarrier set in SL BWP may be used for UL transmission, for example, if the SL transmission is performed, and/or if the SL BWP is activated. At step **2540** of FIG. **25**B, UL signal may be demodulated/decoded. The base station **2101** may demodulate/decode UL signal from the wireless device, for example, based on DC subcarrier information (e.g., the DC subcarrier information received in step **2520**).

At step **2550**, a wireless device may send, to a base station, DC subcarrier information for SL via RRC. At step **2560**, the wireless device may transmit one or more UL signals or one or more SL signals using DC subcarrier for SL, for example, if SL BWP is activated.

FIG. **26** shows an example method for coordinating DC subcarriers between devices. The DC subcarrier of the UL BWP may be changed to match the DC subcarrier of the SL BWP, for example, which may reduce the amount of BWP switching a device performs. For example, by using the base station **2101** to determine the DC subcarrier, all of the wireless devices in coverage of the base station **2101** may use the same DC subcarrier for UL and/or SL communication. Although one or more steps of the example method of FIG. **26** are described for convenience as being performed by the base station **2101**, the wireless device **2503**, and/or the wireless device **2502**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-24**. One or more steps of the example method of FIG. **26** may be rearranged, modified, repeated, and/or omitted.

At step **2605**, the base station **2101** may assign the DC subcarrier of the SL BWP used by the wireless device **2503** (e.g., the wireless device **2503** may be the mode 1 wireless device **2103**) and/or the wireless device **2502** (e.g., the wireless device **2502** may be the mode 2 wireless device **2102**). For example, the base station **2101** may assign both device **2503** and device **2502** to use the same DC subcarrier for SL communications. The DC subcarrier of the SL BWP may be sent (e.g., signaled) to the device **2503** and/or the device **2502** via SIB and/or via RRC messages. Additionally or alternatively, the DC subcarrier information may be preconfigured, for example, for wireless devices that are outside coverage of the base station **2101**. The DC subcarrier information may be preconfigured, for example, so that the SL wireless device uses the same DC subcarrier as the sending (e.g., transmitting) wireless device and the receiving wireless device. At step **2610**, the wireless device **2503** may send a UL signal communication (e.g., transmission) using the SL DC subcarrier indicated by the information received in step **2605**. For example, if the wireless device receives the information indicating the DC subcarrier of the SL BWP, the DC subcarrier set in the SL BWP may be used for the UL communication (e.g., transmission). At step **2615**, the wireless device **2503** may send a SL signal communication (e.g., transmission), to the wireless device **2502**, using the SL DC subcarrier indicated by the information received in step **2605**.

FIG. **27** shows an example method for coordinating communication resources of devices. Although one or more steps of the example method of FIG. **27** are described for convenience as being performed by the base station **2101**, the second wireless device **2703**, and/or the first wireless device **2702**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-26**. One or more steps of the example method of FIG. **27** may be rearranged, modified, repeated, and/or omitted.

At step **2705**, a first wireless device may send (e.g., transmit) an SL signal to a second wireless device. At step **2710**, the second wireless device may receive, from a base station, a message. For example, the message may comprise a SIB, an RRC message, and/or physical layer control signal (e.g. physical layer downlink control channel (PDCCH)). The message may comprise configuration information of a plurality of sets of potential wireless communication reception resources for the first wireless device. At step **2715**, the first wireless device may send higher layer (e.g., a MAC control element and/or an RRC message) and/or physical layer WIRELESS COMMUNICATION control information to the second wireless device, for example, to indicate which set of potential wireless communication reception resources (e.g., SL reception gap) is to be used (e.g., activated). At step **2720**, the second wireless device may determine, based on the indicated set of potential wireless communication reception resources for the first wireless device, one or more communication (e.g., transmission) resources for wireless communication (e.g., transmission) to the first wireless device. At step **2725**, the second wireless device may send (e.g., transmit) a SL signal using the determined resources. For example, a plurality of sets of potential wireless communication reception resources may each comprise different time interval sets indicating time periods during which a wireless communication signal may be received. For example, one or more sets of potential wireless communication reception resources may be configured for the second wireless device. One or more sets of potential wireless communication reception resources may be configured for the first wireless device. For example, the first wireless device may be expected to receive a wireless communication signal within at least one or more configured sets of potential wireless communication resources from the second wireless device.

At step **2730**, the communication (e.g., transmission) resource of the first wireless device may be scheduled by the base station. For example, the first wireless device may be restricted from performing BWP switching within a set of potential wireless communication reception resources. At step **2735**, the second wireless device may determine a communication (e.g., transmission) resource for sending information to the first wireless device. For example, the communication (e.g., transmission) resource may be within at least one set of the potential wireless communication receiving resources in the resource pool selected by the second wireless device. At step **2740**, the second wireless device may determine a communication (e.g., transmission) resource of the second wireless device, wherein the communication (e.g., transmission) resources are selected only from resources that overlap with the indicated set of potential wireless communication resources in the resource pool. The second wireless device may determine that all resources are candidate communication (e.g., transmission) resources in the resource pool selected by the second wireless device, for example, if the second wireless device does not receive configuration information. The second wireless device may determine its communication (e.g., transmission) resource among resources in the resource pool selected by the second wireless device and/or in a plurality of sets of potential wireless communication reception resources, for example, if no higher layer (MAC control element or RRC message) or physical layer wireless communication control information is received from the first wireless device.

A wireless device may receive, from a base stationan RRC message. The RRC message may comprise configuration information of a DC subcarrier for a SL BWP. The wireless device may send (e.g., transmit) a SL signal using the DC subcarrier indicated by the base station.

A wireless device may send (e.g., transmit) one or more RRC messages. The one or more messages may comprise configuration information of DC subcarrier for SL BWP. The base station may receive a UL signal from the wireless device using the SL DC subcarrier. For example, the base station may receive a UL signal using the SL DC subcarrier instead of the DC subcarrier of the UL BWP if the wireless device performs the SL operation and/or if the SL BWP is activated.

FIG. **28** shows an example method for coordinating communication resources of devices. Although one or more steps of the example method of FIG. **28** are described for convenience as being performed by the base station **2101**, the mode 2 wireless device **2102**, and/or the mode 1 wireless device **2103**, one, some, or all of such steps may be performed by one or more other devices (e.g., a base station, a wireless device, a core network device, etc.), and/or steps may be distributed among one or more devices, including any devices such as those described in connection with FIGS. **1-27**. One or more steps of the example method of FIG. **28** may be rearranged, modified, repeated, and/or omitted.

At step **2805**, a switching operation and/or scheduling may be determined. For example, the base station **2101** may determine a Uu BWP switching operation and/or Uu scheduling for the Mode 1 wireless device **2103**. At step **2810**, a SL reception gap and/or scheduling may be determined. The base station **2101** may determine a SL reception gap for the mode 1 wireless device **2103**, for example, based on Uu BWP switching and/or Uu scheduling for the mode 1 wireless device **2103** (e.g., the Uu BWP switching and/or Uu scheduling determined in step **2805**). At step **2815**, the SL reception gap information may be sent (e.g., transmitted). For example, the base station **2101** may send (e.g., transmit) SL reception gap information indicating the SL reception gap determined in step **2810** to the mode 2 wireless device **2102**.

FIG. **29** shows an example method for configuring communication resources of devices. A computer implemented method may include receiving, by a first wireless device from a base station, at least one message comprising: first configuration information of a resource pool for a sidelink operation; and second configuration information of a sidelink reception gap comprising a set of time intervals for allowing reception of a sidelink signal by the second wireless device (step **2905**); determining, by the first wireless device, based on the resource pool and the sidelink reception gap, one or more transmission resources for sidelink signal transmission to the second wireless device (step **2910**); and transmitting, by the first wireless device to the second wireless device, a sidelink signal based on the one or more transmission resources (step **2915**). The second wireless device may be configured to be scheduled by the base station. The first wireless device may not expect the second wireless device to switch a bandwidth part within the sidelink reception gap. The method may further comprise determining, by the first wireless device, one or more transmission resources for the second wireless device within resources overlapping with the sidelink reception gap and the resource pool. The base station may transmit the first message to the first and the second wireless devices via system information block or radio resource control signal. The base station may transmit the second message to the first wireless device via system information block or radio resource control signal. The first wireless device may be configured to select the one or more transmission resources without receiving downlink control information comprising resource assignment for the one or more transmission resources. The sidelink signal transmitted by the first wireless device may comprise a physical layer sidelink control channel and a physical layer sidelink shared channel.

A first wireless device may perform a method comprising multiple operations. The first wireless device may receive, from a base station: an indication of a resource pool for sidelink communication; and an indication of a sidelink reception gap. The first wireless device may determine, based on the resource pool and the sidelink reception gap, at least one resource for sidelink signal transmission to a second wireless device. The first wireless device may send, to the second wireless device and using the at least one resource, a sidelink signal. The first wireless device may send, to the second wireless device, a request to establish a sidelink connection. The first wireless device may receive, from the second wireless device, a response to the request to establish the sidelink connection. The response may comprise sidelink gap information. The determining the at least one resource for sidelink signal transmission to the second wireless device may be further based on the sidelink gap information. The sidelink reception gap may comprise at least one of: a time interval for allowed sidelink signal transmission to the second wireless device; or a time interval for disallowed sidelink signal transmission to the second wireless device. The sidelink reception gap may be associated with at least one time interval during which bandwidth part switching does not occur for the second wireless device. The determining the at least one resource for sidelink transmission to the second wireless device may comprise determining the at least one resource from among at least one resource, of the resource pool, that overlaps with the sidelink reception gap. The receiving the indication of the resource pool for sidelink communication may be via a system information block or via a radio resource control signal. The receiving the indication of the sidelink reception gap may be via a system information block or via a radio resource control signal. The sending the sidelink signal may be via at least one of: a physical layer sidelink control channel; or a physical layer sidelink shared channel. The first wireless device may send, to the base station, information indicating a sidelink direct conversion (DC) subcarrier for the sidelink signal transmission. The first wireless device may send, to the base station, an uplink signal communication via the sidelink DC subcarrier. The wireless device may send, to the base station, information indicating a sidelink DC subcarrier for the sidelink signal transmission. The sending a sidelink signal may comprise sending a sidelink signal via the sidelink DC subcarrier. The first wireless device may receive, from the base station, an indication of a sidelink DC subcarrier to use for uplink and sidelink communication. The first wireless device may send, via the sidelink DC subcarrier, an uplink signal. The first wireless device may receive, from the base station, an indication of a sidelink DC subcarrier to use for uplink and sidelink communication. The sending a sidelink signal may comprise sending a sidelink signal via the sidelink DC subcarrier. The first wireless device may receive, from the base station and via one or more SIB or RRC messages, an indication of a sidelink DC subcarrier to use for uplink and sidelink communication.

Systems, devices, and media may be configured with the method. A wireless device may comprise one or more processors; and memory storing instructions that, when executed, cause the wireless device to perform the described method, additional operations and/or include the additional elements. A system may comprise a wireless device configured to perform the described method, additional operations and/or include the additional elements; and a base station configured to send the indication of a sidelink reception gap. A computer-readable medium may store instructions that, when executed, cause performance of the described method, additional operations and/or include the additional elements.

A first wireless device may perform a method comprising multiple operations. The first wireless device may receive, from a base station: an indication of a resource pool for sidelink communication; and an indication of a sidelink reception gap. The first wireless device may receive, from a second wireless device, a first message associated with establishing a sidelink connection between the first wireless device and the second wireless device. The first wireless device may send, based on the sidelink reception gap, a second message comprising sidelink gap information. The first wireless device may receive, from the second wireless device and using at least one resource associated with the sidelink gap information, a sidelink signal. The first wireless device may determine, based on the resource pool and the sidelink reception gap, the sidelink gap information. The sending the second message may comprise sending, by the first wireless device to the second wireless device, the second message. The sending the second message may comprise sending, by the first wireless device to the base station, the second message. The sidelink reception gap may comprise at least one of: a time interval for allowed sidelink signal transmission to the second wireless device; or a time interval for disallowed sidelink signal transmission to the second wireless device. The sidelink reception gap may be associated with at least one time interval during which bandwidth part switching does not occur for the first wireless device. The receiving the indication of the resource pool for sidelink communication may be via a system information block or via a radio resource control signal. The receiving the indication of the sidelink reception gap may be via a system information block or via a radio resource control signal. The receiving the sidelink signal may be via at least one of: a physical layer sidelink control channel; or a physical layer sidelink shared channel.

Systems, devices, and media may be configured with the method. A wireless device may comprise one or more processors; and memory storing instructions that, when executed, cause the wireless device to perform the described method, additional operations and/or include the additional elements. A system may comprise a first wireless device configured to perform the described method, additional operations and/or include the additional elements; and a second wireless device configured to send the sidelink signal. A computer-readable medium may store instructions that, when executed, cause performance of the described method, additional operations and/or include the additional elements.

A base station may perform a method comprising multiple operations. The base station may send to a first wireless device: an indication of a resource pool for sidelink communication; and an indication of a sidelink reception gap. The base station may receive from a second wireless device, sidelink gap information, wherein the sidelink gap information is associated with the sidelink reception gap. The base station may determine, based on the sidelink gap information, at least one resource assigned to sidelink signal transmission between the first wireless device and the second wireless device. The base station may send, to at least one of the first wireless device or the second wireless device, a downlink signal via resources that do not overlap with the at least one resource assigned to sidelink signal transmission. The sidelink reception gap may comprise at least one of: a time interval for allowed sidelink signal transmission to the second wireless device; or a time interval for disallowed sidelink signal transmission to the second wireless device. The sidelink reception gap may be associated with at least one time interval during which bandwidth part switching does not occur for the second wireless device. The sidelink gap information may indicate the at least one resource, assigned to sidelink signal transmission, from among at least one resource, of the resource pool, that overlaps with the sidelink reception gap. The sending the indication of the resource pool for sidelink communication may be via a system information block or via a radio resource control signal. The sending the indication of the sidelink reception gap may be via a system information block or via a radio resource control signal. The at least one resource assigned to sidelink signal transmission may be for transmission via at least one of: a physical layer sidelink control channel; or a physical layer sidelink shared channel.

Systems, devices, and media may be configured with the method. A computing device may comprise one or more processors; and memory storing instructions that, when executed, cause the computing device to perform the described method, additional operations and/or include the additional elements. A system may comprise a base station configured to perform the described method, additional operations and/or include the additional elements; and a wireless device configured to receive the indication of the sidelink reception gap. A computer-readable medium may store instructions that, when executed, cause performance of the described method, additional operations and/or include the additional elements.

A first wireless device may perform a method comprising multiple operations. The first wireless device may receive, from a base station, at least one message comprising: first configuration information of a resource pool for a sidelink communication; and second configuration information of a sidelink reception gap comprising a set of time intervals for allowing reception of a sidelink signal by a second wireless device. The first wireless device may determine, based on the resource pool and the sidelink reception gap, one or more transmission resources for sidelink signal transmission to the second wireless device. The first wireless device may transmit, to the second wireless device, a sidelink signal based on the one or more transmission resources. The second wireless device may be configured to be scheduled by the base station. The first wireless device may not expect the second wireless device to switch a bandwidth part within the sidelink reception gap. The first wireless device may determine, one or more transmission resources for the second wireless device within resources overlapping with the sidelink reception gap and the resource pool. The base station may transmit the first configuration information to the first wireless device and the second wireless device via system information block or radio resource control signal. The base station may transmit the second configuration information to the first wireless device via system information block or radio resource control signal. The first wireless device may be configured to select the one or more transmission resources without receiving downlink control information comprising resource assignment for the one or more transmission resources. The sidelink signal transmitted by the first wireless device may comprise a physical layer sidelink control channel and a physical layer sidelink shared channel.

FIG. **30** shows example elements of a computing device that may be used to implement any of the various devices described herein, including, e.g., the base station **120**A and/or **120**B, the wireless device **110** (e.g., **110**A and/or **110**B), or any other base station, wireless device, or computing device described herein. The computing device **3000** may include one or more processors **3001**, which may execute instructions stored in the random-access memory (RAM) **3003**, the removable media **3004** (such as a Universal Serial Bus (USB) drive, compact disk (CD) or digital versatile disk (DVD), or floppy disk drive), or any other desired storage medium. Instructions may also be stored in an attached (or internal) hard drive **3005**. The computing device **3000** may also include a security processor (not shown), which may execute instructions of one or more computer programs to monitor the processes executing on the processor **3001** and any process that requests access to any hardware and/or software components of the computing device **3000** (e.g., ROM **3002**, RAM **3003**, the removable media **3004**, the hard drive **3005**, the device controller **3007**, a network interface **3009**, a GPS **3011**, a Bluetooth interface **3012**, a WiFi interface **3013**, etc.). The computing device **3000** may include one or more output devices, such as the display **3006** (e.g., a screen, a display device, a monitor, a television, etc.), and may include one or more output device controllers **3007**, such as a video processor. There may also be one or more user input devices **3008**, such as a remote control, keyboard, mouse, touch screen, microphone, etc.

The computing device **3000** may also include one or more network interfaces, such as a network interface **3009**, which may be a wired interface, a wireless interface, or a combination of the two. The network interface **3009** may provide an interface for the computing device **3000** to communicate with a network **3010** (e.g., a RAN, or any other network). The network interface **3009** may include a modem (e.g., a cable modem), and the external network **3010** may include communication links, an external network, an in-home network, a provider's wireless, coaxial, fiber, or hybrid fiber/coaxial distribution system (e.g., a DOCSIS network), or any other desired network. Additionally, the computing device **3000** may include a location-detecting device, such as a global positioning system (GPS) microprocessor **3011**, which may be configured to receive and process global positioning signals and determine, with possible assistance from an external server and antenna, a geographic position of the computing device **3000**.

The example in FIG. **30** may be a hardware configuration, although the components shown may be implemented as software as well. Modifications may be made to add, remove, combine, divide, etc. components of the computing device **3000** as desired. Additionally, the components may be implemented using basic computing devices and components, and the same components (e.g., processor **3001**, ROM storage **3002**, display **3006**, etc.) may be used to implement any of the other computing devices and components described herein. For example, the various components described herein may be implemented using computing devices having components such as a processor executing computer-executable instructions stored on a computer-readable medium, as shown in FIG. **30**. Some or all of the entities described herein may be software based, and may co-exist in a common physical platform (e.g., a requesting entity may be a separate software process and program from a dependent entity, both of which may be executed as software on a common computing device).

The disclosed mechanisms herein may be performed if certain criteria are met, for example, in a wireless device, a base station, a radio environment, a network, a combination of the above, and/or the like. Example criteria may be based on, for example, wireless device and/or network node configurations, traffic load, initial system set up, packet sizes, traffic characteristics, a combination of the above, and/or the like. If the one or more criteria are met, various examples may be used. It may be possible to implement examples that selectively implement disclosed protocols.

A base station may communicate with a mix of wireless devices. Wireless devices and/or base stations may support multiple technologies, and/or multiple releases of the same technology. Wireless devices may have some specific capability(ies) depending on wireless device category and/or capability(ies). A base station may comprise multiple sectors. A base station communicating with a plurality of wireless devices may refer to base station communicating with a subset of the total wireless devices in a coverage area. Wireless devices referred to herein may correspond to a plurality of wireless devices of a particular LTE or 5G release with a given capability and in a given sector of a base station. A plurality of wireless devices may refer to a selected plurality of wireless devices, and/or a subset of total wireless devices in a coverage area. Such devices may operate, function, and/or perform based on or according to drawings and/or descriptions herein, and/or the like. There may be a plurality of base stations or a plurality of wireless devices in a coverage area that may not comply with the disclosed methods, for example, because those wireless devices and/or base stations perform based on older releases of LTE or 5G technology.

One or more features described herein may be implemented in a computer-usable data and/or computer-executable instructions, such as in one or more program modules, executed by one or more computers or other devices. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types when executed by a processor in a computer or other data processing device. The computer executable instructions may be stored on one or more computer readable media such as a hard disk, optical disk, removable storage media, solid state memory, RAM, etc. The functionality of the program modules may be combined or distributed as desired. The functionality may be implemented in whole or in part in firmware or hardware equivalents such as integrated circuits, field programmable gate arrays (FPGA), and the like. Particular data structures may be used to more effectively implement one or more features described herein, and such data structures are contemplated within the scope of computer executable instructions and computer-usable data described herein.

Many of the elements in examples may be implemented as modules. A module may be an isolatable element that performs a defined function and has a defined interface to other elements. The modules may be implemented in hardware, software in combination with hardware, firmware, wetware (i.e., hardware with a biological element) or a combination thereof, all of which may be behaviorally equivalent. For example, modules may be implemented as a software routine written in a computer language configured to be executed by a hardware machine (such as C, C++, Fortran, Java, Basic, Matlab or the like) or a modeling/simulation program such as Simulink, Stateflow, GNU Octave, or LabVIEWMathScript. Additionally or alternatively, it may be possible to implement modules using physical hardware that incorporates discrete or programmable analog, digital and/or quantum hardware. Examples of programmable hardware may comprise: computers, microcontrollers, microprocessors, application-specific integrated circuits (ASICs); field programmable gate arrays (FPGAs); and complex programmable logic devices (CPLDs). Computers, microcontrollers, and microprocessors may be programmed using languages such as assembly, C, C++ or the like. FPGAs, ASICs, and CPLDs may be programmed using hardware description languages (HDL), such as VHSIC hardware description language (VHDL) or Verilog, which may configure connections between internal hardware modules with lesser functionality on a programmable device. The above-mentioned technologies may be used in combination to achieve the result of a functional module.

A non-transitory tangible computer readable media may comprise instructions executable by one or more processors configured to cause operations of multi-carrier communications described herein. An article of manufacture may comprise a non-transitory tangible computer readable machine-accessible medium having instructions encoded thereon for enabling programmable hardware to cause a device (e.g., a wireless device, wireless communicator, a wireless device, a base station, and the like) to allow operation of multi-carrier communications described herein. The device, or one or more devices such as in a system, may include one or more processors, memory, interfaces, and/or the like. Other examples may comprise communication networks comprising devices such as base stations, wireless devices or user equipment (wireless device), servers, switches, antennas, and/or the like. A network may comprise any wireless technology, including but not limited to, cellular, wireless, WiFi, 4G, 5G, any generation of 3GPP or other cellular standard or recommendation, wireless local area networks, wireless personal area networks, wireless ad hoc networks, wireless metropolitan area networks, wireless wide area networks, global area networks, space networks, and any other network using wireless communications. Any device (e.g., a wireless device, a base station, or any other device) or combination of devices may be used to perform any combination of one or more of steps described herein, including, for example, any complementary step or steps of one or more of the above steps.

Although examples are described above, features and/or steps of those examples may be combined, divided, omitted, rearranged, revised, and/or augmented in any desired manner Various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this description, though not expressly stated herein, and are intended to be within the spirit and scope of the descriptions herein. Accordingly, the foregoing description is by way of example only, and is not limiting.

What is claimed is:

1. A method comprising:

receiving, by a first wireless device from a base station:

an indication of a resource pool for sidelink communication; and

an indication of a time interval for disallowed sidelink signal transmission;

determining, by the first wireless device, at least one resource, outside the time interval and from the resource pool, for sidelink signal transmission to a second wireless device; and

sending, by the first wireless device to the second wireless device using the at least one resource, a sidelink signal.

2. The method of claim **1**, further comprising:

sending, by the first wireless device to the second wireless device, a request to establish a sidelink connection; and

receiving, by the first wireless device from the second wireless device, a response to the request to establish the sidelink connection, wherein the response comprises sidelink gap information, and wherein the determining the at least one resource for sidelink signal transmission to the second wireless device is further based on the sidelink gap information.

3. The method of claim **1**, further comprising:

receiving, by the first wireless device from the base station, an indication of a second time interval for allowed sidelink signal transmission to the second wireless device.

4. The method of claim **1**, wherein, during the time interval, bandwidth part switching occurs for the second wireless device.

5. The method of claim **1**, wherein the determining the at least one resource for sidelink signal transmission to the second wireless device comprises determining the at least one resource from among at least one resource, of the resource pool, that overlaps with a sidelink reception gap associated with the time interval.

6. The method of claim **1**, wherein the receiving the indication of the resource pool for sidelink communication and the indication of the time interval is via a system information block or via a radio resource control signal.

7. The method of claim **1**, wherein the sending the sidelink signal is via at least one of:

a physical layer sidelink control channel; or

a physical layer sidelink shared channel.

8. A first wireless device comprising:

one or more processors; and

memory storing instructions that, when executed by the one or more processors, configure the first wireless device to:

receive, from a base station:

an indication of a resource pool for sidelink communication; and

an indication of a time interval for disallowed sidelink signal transmission;

determine at least one resource, outside the time interval and from the resource pool, for sidelink signal transmission to a second wireless device; and

send, to the second wireless device using the at least one resource, a sidelink signal.

9. The first wireless device of claim **8**, wherein the instructions, when executed by the one or more processors, further configure the first wireless device to:

send, to the second wireless device, a request to establish a sidelink connection; and

receive, from the second wireless device, a response to the request to establish the sidelink connection, wherein the response comprises sidelink gap information, and

wherein the instructions, when executed by the one or more processors, configure the first wireless device to determine the at least one resource for sidelink signal transmission to the second wireless device further based on the sidelink gap information.

10. The first wireless device of claim **8**, wherein the instructions, when executed by the one or more processors, further configure the first wireless device to:

receive, from the base station, an indication of a second time interval for allowed sidelink signal transmission to the second wireless device.

11. The first wireless device of claim **8**, wherein, during the time interval, bandwidth part switching occurs for the second wireless device.

12. The first wireless device of claim **8**, wherein the instructions, when executed by the one or more processors, configure the first wireless device to determine the at least one resource for sidelink signal transmission to the second wireless device by determining the at least one resource from among at least one resource, of the resource pool, that overlaps with a sidelink reception gap associated with the time interval.

13. The first wireless device of claim **8**, wherein the instructions, when executed by the one or more processors, configure the first wireless device to receive the indication of the resource pool for sidelink communication and the indication of the time interval via a system information block or via a radio resource control signal.

14. The first wireless device of claim **8**, wherein the instructions, when executed by the one or more processors, configure the first wireless device to send the sidelink signal via at least one of:

a physical layer sidelink control channel; or

a physical layer sidelink shared channel.

15. A non-transitory computer-readable medium storing instructions that, when executed, configure a first wireless device to:

receive, from a base station:

an indication of a resource pool for sidelink communication; and an indication of a time interval for disallowed sidelink signal transmission;

determine at least one resource, outside the time interval and from the resource pool, for sidelink signal transmission to a second wireless device; and

send, to the second wireless device using the at least one resource, a sidelink signal.

16. The non-transitory computer-readable medium of claim **15**, wherein the instructions, when executed, further configure the first wireless device to:

send, to the second wireless device, a request to establish a sidelink connection; and

receive, from the second wireless device, a response to the request to establish the sidelink connection, wherein the response comprises sidelink gap information, and

wherein the instructions, when executed, configure the first wireless device to determine the at least one resource for sidelink signal transmission to the second wireless device further based on the sidelink gap information.

17. The non-transitory computer-readable medium of claim **15**, wherein the instructions, when executed, further configure the first wireless device to:

receive, from the base station, an indication of a second time interval for allowed sidelink signal transmission to the second wireless device.

18. The non-transitory computer-readable medium of claim **15**, wherein, during the time interval, bandwidth part switching occurs for the second wireless device.

19. The non-transitory computer-readable medium of claim **15**, wherein the instructions, when executed, configure the first wireless device to determine the at least one resource for sidelink signal transmission to the second wireless device by determining the at least one resource from among at least one resource, of the resource pool, that overlaps with a sidelink reception gap associated with the time interval.

20. The non-transitory computer-readable medium of claim **15**, wherein the instructions, when executed, configure the first wireless device to receive the indication of the resource pool for sidelink communication and the indication of the time interval via a system information block or via a radio resource control signal.

21. The non-transitory computer-readable medium of claim **15**, wherein the instructions, when executed, configure the first wireless device to send the sidelink signal via at least one of:

a physical layer sidelink control channel; or

a physical layer sidelink shared channel.

22. A system comprising:

a first wireless device; and

a base station configured to:

send, to the first wireless device:

an indication of a resource pool for sidelink communication; and

an indication of a time interval for disallowed sidelink signal transmission,

wherein the first wireless device is configured to:

determine at least one resource, outside the time interval and from the resource pool, for sidelink signal transmission to a second wireless device; and

send, to the second wireless device using the at least one resource, a sidelink signal.

23. The system of claim **22**, wherein the first wireless device is further configured to:

send, to the second wireless device, a request to establish a sidelink connection; and

receive, from the second wireless device, a response to the request to establish the sidelink connection, wherein the response comprises sidelink gap information, and

wherein the first wireless device is configured to determine the at least one resource for sidelink signal transmission to the second wireless device further based on the sidelink gap information.

24. The system of claim **22**, wherein the first wireless device is further configured to:

receive, from the base station, an indication of a second time interval for allowed sidelink signal transmission to the second wireless device.

25. The system of claim **22**, wherein, during the time interval, bandwidth part switching occurs for the second wireless device.

26. The system of claim **22**, wherein the first wireless device is configured to determine the at least one resource for sidelink signal transmission to the second wireless device by determining the at least one resource from among at least one resource, of the resource pool, that overlaps with a sidelink reception gap associated with the time interval.

27. The system of claim **22**, wherein the base station is configured to send the indication of the resource pool for sidelink communication and the indication of the time interval via a system information block or via a radio resource control signal.

28. The system of claim **22**, wherein the first wireless device is configured to send the sidelink signal via at least one of:

a physical layer sidelink control channel; or

a physical layer sidelink shared channel.

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